INTEGRATED WATERSHED MANAGEMENT: CHINA-WIDE ANALYSIS AND A CASE STUDY IN THE MIN RIVER BASIN, FUJIAN, CHINA

by

GUANGYU WANG

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ABSTRACT

China's watershed management policy and its forest tenure have undergone remarkable changes since the devastating floods of 1998. The government has launched key national programs and forest policy reforms, such as large-scale plantation and reforestation, logging bans in natural forests, land ownership reforms, and comprehensive flood control systems. The scale and investment of these programs are already producing tangible benefits to forest cover, the forest industry and rural livelihoods, yet the transition of China's forestry sector to a sustainable operation remains in doubt.

Watershed issues are complex and multidimensional. Forest management was for a long time viewed as contributing to environmental protection. However, forestry can be both positive and negative. Sustainable forest management is critical for forest-dependent communities in a forest-dominated watershed such as that of the Min River. The research presented here uses the Min River Watershed (Fujian, China) to examine aspects of watershed sustainability. Several topics are examined, including the effects of conventional forest practices on land degradation; the current state of bamboo forest resources and management in the watershed and the role of the bamboo forest industry in social development, economic growth and ecosystem protection; the impact of infrastructure development on soil erosion; patterns of land-use change in the Min River over the last 20 years using Landsat imagery; and public perceptions of watershed management in the watershed. This work has been placed into a broader context by examining current forest policies and their relation to environmental protection programs in China. Particular emphasis has been placed on the evaluation of forest policy and national programs to combat flooding.

Watersheds are holistic systems where social, cultural, economic and environmental issues interact. Forestry is only one of several factors affecting watershed sustainability. Watershed management is a complex, dynamic and continually improving process. It needs to bring together personnel from diverse disciplines, to integrate data from multiple dimensions and to develop a comprehensive management tool that will enable managers, stakeholders and third party interest groups to work together more effectively in solving watershed problems.

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PREFACE

This dissertation follows a manuscript-based format that is constructed around eight related manuscripts of which I am the senior co-author. The major contribution in this dissertation has come from results of the Min River Watershed Project (MRWP) which was funded by Fujian government to fill a major knowledge gap about the linkage between sustainable forest management (SFM) and integrated watershed management. While each of the eight manuscripts deals with a key issue related to watershed management, they all adopt a SFM approach to promote integrated watershed management. This research work was motivated by the 1998 devastating flooding in China.

In the summer of 1998, while I was still enjoying the beautiful weather of the Pacific Northwest and completing my business degree in Oregon, USA, I dedicated myself to be a facilitator in the globalization of China's forestry. At that moment, China was preparing intensively for its entry into the World Trade Organization. The Emerging Wood Markets Series of Conferences – China as an Emerging Wood Market – at the World Forest Institute in Portland, Oregon, attracted hundreds of entrepreneurs from North America and Asia. As one of the organisers, I felt that it was good timing for me to use my knowledge to help China's forestry sector to adapt globalization. However, that summer, devastating flooding affected much of China. The Yellow, Yangtze, Songhua, Nen, Zhu, Min, Gan, and Huai Rivers were paralysed. Millions of people fought to protect levées, cities, houses, and their lives. In the largest natural disaster in China of the 20th century, 3004 people were killed, and 29 provinces, 20 million ha. of land, 5 million houses and 223 million people were affected. The damage was estimated to be in excess of US$ 30 billion.

As a direct result of this disaster, I decided to shift my career path to sustainable watershed management. After I was accepted as a PhD student to pursue my Environmental Science degree at the Oregon Graduate Institute of Science and Technology, I chose to go back to China to undertake field research, rather than undertaking a study that would be largely theoretical. During those four years of research, as one of the leaders in watershed management in the Fujian Provincial Government, I worked in a small watershed, namely the Jiulong River Watershed, in Zhangzhou, Fujian. This work started a program of forest restoration and sustainable development that was subsequently awarded the third prize in Science and Technology Progress Achievements by the Fujian Provincial Government. I then moved to the Min River Watershed, the largest watershed in Fujian Province, where I was supported by the Fujian Provincial Government and many international bodies, such as the World Bank. However, I knew that I was struggling to keep my knowledge of sustainable forest management and watershed management up to date, and my work was also being compromised by my inability to use advanced technologies such as GIS, remote sensing and a range of policy analysis and decision-making tools. As a result, I decided to join the Sustainable Forest Management Group at the University of British Columbia to continue my research. That explains who I am, how I came to be at UBC, and why I have undertaken the research that is detailed in this thesis.

During the last five years, supported by my research team in Fujian, and helped by my 'SFM Lab' colleagues at UBC, and particularly by my supervisor Professor John Innes, and by my academic advisory committee – Dr. Yongyuan Yin, Dr. Sarah Gergel and Dr. Markus Weiler, the research was completed in 2007 and awarded a Gold Prize in Science and Technology Progress Achievements by the Fujian Provincial Government in 2008 and nominated to the Ministry of

Science and Technology, China, for a national scientific award. Some of the results have already been adopted in provincial planning, specifically the Min River Watershed Water Environmental Planning (2005–2020), and the Strategic Plans for Environmental Protection of Fujian Province.

The research was a collaborative effort, and what I have undertaken represents only a third of the overall project. This thesis presents the research that I led (watershed assessment and integration), and I would like to thank my colleagues, Professor Wei Hong and Dr. Hongfu Ye for their support and for sharing the results from their part of the research project with me.

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I would like to take this opportunity to write some deep and beautiful words, the words from the bottom of my heart to convey my gratitude to all who have made my venture happen and my long desired dream to come true.

First, I am grateful to the Min River – the mother river of the Fujianese. I love her peace and selflessness to nourish her children. While walking along the river bank of the Fuzhou Riverfront Park, watching and listening to the purring of the Min River, I seemed to see a mother embracing her children and reading to them a beautiful story. I love her prettiness, her generosity, and her. However, I fear her anger and her power that is sometimes used to punish our greediness and wrong-doing, and which has taught me how precious what I have is today, how to share my wealth with others and how to preserve the environment for our generation and for generations to come.

First and foremost, I want to “xie xie” (谢谢!) to Dr. John Innes, my supervisor for his great support. Without his help, this thesis would not have been possible. John, thank you so much for all your patience and tirelessness in helping me in all the time of research for and writing of this thesis.

I am also grateful to Dr. Yin Yuanyong, Dr. Sarah Gergel, and Dr. Markus Weiler for their kindness, encouragement and support throughout my PhD program. When I found it hard to understand awkward concepts or the complex and often counter-intuitive rules involved in playing the games associated with this academic world, they have always been available to provide advice.

My thanks also go to the faculty members at UBC forestry, where I took or audited almost all the graduate course under the “FRST” category. I particularly want to thank Dr. Sarah Gergel, Dr. Markus Weiler, Dr. Nicholas Coops, Dr. Hamish Kimmins, Dr Valerie LeMay, Dr. David Tait, Dr. David Tindall and Dr. Stephen Sheppard for helping me with my course work. My research has greatly benefited from my improved understanding of watershed management, landscape ecology, social science, advanced statistics and remote sensing technology.

I would like to thank my superior, Mr. Liu Dezhang, Executive Vice Governor of Fujian Province for his long-term support and friendship. I also would like to give all my thanks to my colleagues Professor Wei Hong, Executive Vice President of Fujian Agriculture and Forestry University, and Dr. Hongfu Ye, Vice President of Fujian Academy of Forestry and my whole research team in Fujian. Without their kind help, I could not have accomplished so much. I sincerely thank the many anonymous referees for their extremely helpful comments on my earlier manuscripts that led to a great improvement in the quality of these eight papers.

Lastly, I want to thank my research funding organizations – the Fujian Provincial Government, the Fujian Department of Science and Technology, the Fujian Natural Science Foundation, the Canadian Social Sciences and Humanities Research Council (SSHRC), the Mary and David Macaree Fellowship, the Namkoong Family Fellowship, and the Vandusen Graduate Fellowship. With their support, I was able to focus on my research.

CO-AUTHORSHIP STATEMENT

Chapter 2: (Paper I: Watershed management in China: Past, present and future development)
- I conducted the literature review, data analyses and manuscript preparation;
- Dr. John Innes provided helpful discussion, clarified many of historical details, and improved the quality of the English.

Chapter 3: (Paper II: Major challenges facing the sustainability of the forest sector in China)
- I conducted the literature review, data analyses and manuscript preparation;
- Dr. John Innes provided guidance and improved the quality of the paper;
- Dr. Dai Shuanyou helped with forest policy reform data;
- Dr. Sara Wu provided comments on the international wood trade analysis.

Chapter 4: (Paper III: China's forestry reforms)
- I performed the research, data analyses and manuscript preparation;
- Dr. John Innes revised and finalized the paper;
- Dr. Shuanyou Dai and Deputy Minister Jiafu Lei provided China national forest policy and program development data, and many helpful comments;
- Sara Wu helped with the international impact analysis

Chapter 5: (Paper IV: Achieving sustainable rural development in Southern China: Perspectives from bamboo forestry)
- I identified and designed the research, collected and analyzed data and prepared the draft manuscript;
- Dr. John L. Innes provided guidance and finalized the paper;
- Dr. Shuangyou Dai helped with national bamboo data collection;
- Dr. Guohui He helped with partial ground data collection in Fujian.

Chapter 6: (Paper V: Watershed pattern and change in land-use in the Min River Watershed, Fujian)
- I identified and designed the research methods, collected remote sensing data, conducted partial analyses and prepared the manuscript;
- Dr. John Innes provided comments on the content and improved the quality of the English;
- Dr. Jian Liu and Dr. Kunyong Yu helped with ground data collection from Fujian and provided field data analysis;
- Dr. Karen Yan helped with the GIS data analyses.

Chapter 7: (Paper VI: Extent of soil erosion associated with large-scale infrastructure development and possible amelioration measures)

The research was initiated and designed by Professor Yang Yusheng, Dr. Chen Shanmu, Dr. Xie Jingsheng and Dr. Lin Wenlian from Fujian Normal University and Fujian Soil and Water Monitory Station. The data from the large-scale construction sites for 1999-2004 were mainly collected by them;

- I worked with them to conduct data analyses and prepared the draft manuscript.
- Dr. John L. Innes provided helpful discussions and clarified many of hydrological details, and improved the content and quality of the paper.

Chapter 8: (Paper VII: Public awareness and conception on Min River watershed management and development, Fujian, China)

- I identified the research and designed the research methodology and questionnaire, analyzed the data and prepared the draft manuscript;
- Dr. Xiaoping Zhang helped with questionnaire pre-test in Fuzhou National Park and trained the field assistants;
- Ms. Jingxin Wang helped with data entry and some of the analysis;
- Dr. John Innes provided guidance and finalized the paper.

Chapter 9: (Paper VIII: Watershed sustainability: Strategic and tactical level assessment in the Min River watershed, China)

- I initiated and led the research while I was chairing the Min River Watershed sustainable watershed management project at Fujian Department of Forestry, just before coming to UBC. The assessment involved with more than thirty professionals from different disciplines. I undertook the data analyses and manuscript preparation at UBC.
- Dr. John Innes provided guidance and helpful discussions on sustainable forest management and forest certification, and did the paper revision and improvement.

1 INTRODUCTION

People in China still remember the disasters that occurred during the summer of 1998. The country was ravaged by devastating floods – the Yellow, Yangtze, Songhua, Nen, Zhu, Min, Gan, and Huai River were all affected. Millions of people fought to protect levées, cities, lands, houses, and their lives. In this largest natural disaster of the 20th century in China, across 29 provinces, 20 million ha land and 5 million houses were flooded, 223 million people were affected and 3004 people were killed. The overall damage was estimated to be in excess of US$ 30 billion (FAO and CIFOR 2005).

Over-logging, deforestation, mismanagement … the forestry sector was blamed for the disaster. A logging ban was soon imposed in all natural forests in the headwaters of the rivers, with thousands of workers losing their jobs and half a million people being re-located. A series of environmental protection programs were launched, including the Natural Forest Protection Program, the Conversion Program from Cropland to Forest and Grass, the Shelterbelt Development Program along the Yangtze River Basin, and the Wildlife Conservation and Nature Reserves Development Program. Billions dollars were and still are being invested in planting trees (Wang *et al*., 2007).

However, since 2000, China has continued to suffer from massive social, economic and environmental damage resulting from the devastating floods that have occurred every year. Between January and August 2004, 46 million people were affected by flooding in China (FAO and CIFOR 2005). Lack of scientific support for the protection programs has also created many problems and has resulted in a number of negative impacts (Chen, 2000; Fujian Environmental Protection Bureau, 2005 and Hong, 2005). A plethora of meetings and reports indicates that governments, communities and citizens are increasingly asking how environmental degradation can be harnessed, how watershed ecosystems can be restored and how sustainable development can be achieved.

The sustainable watershed development is a complex problem that involves many different facets, including the social, economic, environmental and cultural needs of a designated area. Managers need to balance the interests of all stakeholders to ensure that any development is towards regional sustainability, while at the same time minimizing any impacts on other areas. In much of China, forests represent a key natural resource in a watershed development. Sound forest management is needed not only to stabilize regional ecosystems, but also to provide habitat for wildlife, to supply food, water, wood and many goods and services, and to promote community social, cultural and economic development. However, these functions can only be fulfilled if forest management is undertaken appropriately.

The research presented here is part of a regional research project undertaken in Southeast China called “Study of Sustainable Management on the Min River Watershed”, which was initiated by the Fujian Provincial Government. The aim of the project was to provide sustainable watershed management principles and techniques for the Fujian Provincial Government so that it could fulfill the goal of constructing the Fujian Eco-province.

1.1 SUSTAINABLE WATERSHED MANAGEMENT

A watershed is a topographically delineated area that is drained by a river system. A watershed is also a hydrological response unit, a biophysical unit, and a holistic ecosystem in terms of the materials, energy and information that flow through the watershed. A watershed can be seen as a multiple-use pool of common resources (Steins and Edward, 1999) that can be used for agriculture, manufacturing and other human activities (Wright and Padgitt, 2005). In this thesis, I consider watershed management to be the interdisciplinary integration of the physical, biological, chemical, social, economic, and political sciences in organizing and guiding land, water and other natural resource use in a watershed. Its objective is to provide appropriate goods and services while mitigating the impact on the soil and watershed resources. This involves investigating and managing the socioeconomic, human-institutional, and biophysical inter-relationships among soil, water, and land use and the connections between the different areas within the watershed.

The concept of watershed management is very old. The Atharva Veda text from 800 B.C. contains what may well be the first written reference to watershed management. Atharva Veda verse 19, 2.1 states that: "…one should take proper managerial action to use and conserve water from mountains, wells, rivers and also rainwater for use in drinking, agriculture, industries…" (cited in Chandra, 1990). In the West, the need for watershed management was recognized by Benjamin Franklin as early as 1790 (Davenport, 2003). John Wesley Powell (1890) proposed to the US Congress that the western states should be organized and governed with watershed boundaries rather than straight-line political boundaries (Mcginnis *et al.*, 1999). However, watershed management as a holistic concept was not defined until the mid 20th century. The International Glossary of Hydrology (WMO/UNESO, 1969) presented a very simple definition of watershed management, stating that watershed management is the "…planned use of drainage basins in accordance with pre-determined objectives" (p. 138). Influenced by multiple-use philosophy and the importance of water as a commodity, Dortignac (1967), Head of the Water Resource Branch of the U.S. Forest Service, stated that: "Watershed management can play an important role under the present increasing population pressures and the public demand for greater productivity and multiple uses of forest and related lands. Scientific prescriptions that utilize the wood, forage, wildlife and recreation resources as well as improve water yields and control, maintain, or improve soil stability provide the means" (p.585). Such statements emphasize the importance of looking at multiple uses of watershed resources, rather than simply the hydrology.

There are several issues facing watershed management worldwide, ranging from fundamental concerns over land-use needs and demands to more aesthetic and recreational needs. As with any form of resource management, the issues can be classified into a number of categories, including the policy and tenure system, equity, gender, participation, institution building, and research and development. Tension between the many different users – agriculture, forestry, industries, power, mines, urban and rural consumers, amenity, ecology and environment – exist in many parts of world (Calder, 1999). Calder points out that the right of access to water and equity considerations are key issues in some countries. Although land-use and water resources issues and concerns are often as diverse as the different countries' cultures, economies and stage of technical development, there appears to be some commonality in the way that governments treat the issues. These common issues tend to focus on how to minimize the impact of watershed development without compromising the needs of all stakeholders in the watershed. Obstacles to this process mainly seem to arise from: 1) divisions associated with political boundaries; 2) lack of interagency communication and cooperation; 3) lack of mutual support among different areas, especially between upstream and downstream reaches; and 4) lack of public participation. Other problems include changes in administrations and their policies, lack of data, corruption, bureaucracy and debt (Krairapanond and Atkinson, 1998).

Barry (1997) has written about the great Mississippi flood of 1927 and the struggles of "man against nature" and "man against man". The story illustrates the human storm that accompanied the flood. "Honour and money collided. White and black collided. Regional and national power structures collided" (p.17). Hurricane Katrina in New Orleans in 2005 repeated the events of 1927. The science of watershed management is not just the science of hydrology, biology, physics, agronomy, botany, climatology, watershed ecology and engineering – it has also become the science of society and the study of the tensions among people, communities and their perceptions of what ought to be (Wright and Padgitt, 2005).

A common problem for watershed research is that some of the data needed for holistic assessments are frequently missing, reflecting the multi-sectorial nature of the research. Without complete data, it is difficult to identify the main issues and establish an effective management plan. The difficulty in developing a Decision Support System (DSS) is not the lack of available simulation models but rather making these models available to decision makers, a key finding of the National Resource Council's Committee on Watershed Management (1999).

Watershed management approaches have been adopted under a wide range of political, economic, social and environmental circumstances. Although there are many similarities in watershed management and research around the world, there remain some fundamental differences, such as the driving forces behind many of the processes, and cultural differences. For example, in comparing China with Canada, it is evident that the driving forces toward sustainable watershed management differ. In Canada, they primarily come from public interest groups, such as Environmental Non-Governmental Organizations (ENGOs), local communities and individuals, and the pressures are for the supply of clean drinking water and the maintenance of healthy ecosystems (Naimann *et al*., 2000; Davies and Mazumder, 2003). In China the driving forces are primarily from the governments, conflicts over water use and intensification of land, in addition to the financial losses and social unrest arising from devastating flooding, pollution and land degradation. The pressures arise from concerns about and threats to the safety of people's lives and property.

SFM and Watershed Management

In recent decades, a strong global consensus has begun to develop around the notion that watersheds are the best unit for the management not only of water resources but of ecosystems in general (Montgomery *et al*., 1995). In addition, management of water resources has become one of the key criteria associated with sustainable forest management. Criterion Five of the Helsinki Process (1994), which lists a number of criteria related to sustainable forest management, is to "Maintain and develop the role of forests in water supply and protection against erosion", and Criterion 4 of the Montreal Process (1995), which also lists criteria for sustainable forest management, relates to the "Conservation and maintenance of soil and water resources". Both have selected soil and water resources as key conditions of sustainability. Eight out of 67 indicators selected in the Montreal Process pertain to soil, watershed condition and quantity and quality of water resources. They are: a) Area and percent of forest land with significant soil erosion; b) Area and percent of forest land managed primarily for protective functions, e.g., watersheds, flood protection, avalanche protection, riparian zones; c) Percent of stream kilometres in forested catchments in which stream flow and timing has significantly deviated from the historic range of variation; d) Area and percent of forest land with significantly diminished soil organic matter and/or changes in other soil chemical properties; e) Area and percent of forest land with significant compaction or change in soil physical properties resulting from human activities; f) Percent of water bodies in forest areas (e.g., stream kilometres, lake hectares) with significant variance of biological diversity from the historic range of variability; g) Percent of water bodies in forest areas (e.g., stream kilometres, lake hectares) with significant variation from the historic range of variability in pH, dissolved oxygen, levels of chemicals (electrical conductivity), sedimentation or temperature change; and h) Area and percent of forest land experiencing an accumulation of persistent toxic substances

Now, many countries are trying to place water management within the context of natural and human systems (Heathcote, 1998 and 2009; Gearey and Jeffrey, 2006). The World Bank, amongst others, uses watershed management approaches to assess the environmental benefits of development projects (Brooks et al., 1992; Tennyson, 2003). The World Bank has recognized that, as part of a watershed management approach, people are affected by the interaction of water with other resources and that they influence the nature and magnitude of those interactions. Poor ecosystem management within watersheds has and will result in the impaired functioning of the watershed, which in fragile environments can lead to ecosystem collapse (Samra and Eswaran, 1997; Hong, 2000; Yang et al., 2006).

Tools for Integrated Watershed Management

Watershed management appears to have moved from a focus on physical water and soil conservation to the integration of social, economic, and environmental development. Watershed management assessment therefore requires the integration of a vast array of spatial information and temporal data. The modeling and visualization capabilities of modern GIS, coupled with the explosive growth of the Internet and the World Wide Web, offer new tools to understand the processes and dynamics that shape the physical, biological and chemical environment of watersheds. The linkage between GIS, the Internet, and environmental databases is especially helpful in planning studies, where information exchanges and timely feedback are crucial, especially when several different agencies and stakeholders are involved (Tim, 2003). A number of integrated watershed management tools have been discussed in the recent literature (e.g., Ffolliottee et al, 2002; Westervelt, 2003, Davenport, 2003, Singh and Frevert, 2006 and Heathcote, 2009), and some of these are described below.

Watershed simulation modeling: Watershed modeling, or hydrologic simulation, began in the 1950s and 1960s, and with the advent and rapid progress in digital computer technologies, numerical simulation models have become increasingly important and effective tools for tackling a wide range of environmental and resource management issues (Choen, 2004). Included among these many types of models are watershed hydrological models that simulate the dynamic behaviour of significant flow and storage processes and generate water balance information (quantity and associated hydraulic characteristics, sources and pathways, residence times, etc.). Historically, most early hydrological models were designed to estimate water quantities in engineering applications such as flood forecasting, urban storm water management and other water resources planning activities such as reservoir design and water supply. The

Stanford Watershed Model (SWM) was one of the first such programs; it was developed to replace the tedious manual computations performed by hydrologists to predict stream flow given observed precipitation (and other meteorological variables) (Donigian and Imhoff, 2006). Since the late 1970s, water quality components have been developed and incorporated into some watershed models as the importance of non-point source pollution has been gradually recognized (Chen, 2004). Models such as BASINS have been developed to meet the increasingly demanding regulatory framework for water in watersheds (Duda *et al*., 2006), and increasing use is being made of such approaches. In 1995, Vijay Singh edited a book entitled *Computer Models of Watershed Hydrology* which contained 26 of the most popular models that have been adopted worldwide. In 2002, Vijay Singh and Donald Frevert edited two books entitled *Mathematical Models of Large Watershed Hydrology* and *Mathematical Models of Small Watershed Hydrology and Application*. In the latest book edited by Singh and Frevert (2006), entitled *Watershed Models*, 24 of the most commonly used models were selected on the basis of a wide range of characteristics, such as representativeness, comprehensiveness and broad-based applications. These reviews provide ample evidence of the very rapid development that has occurred in the field of watershed modeling.

'Simulation Modeling for Watershed Management' (Westervelt, 2003) provides a means for users to use computer modeling for simulating watershed management. Software is not yet generally available for the development of large, complex, and computationally-intensive, spatially-explicit, simulation models. However, many alternatives are available. The Spatial Modeling Environment (SME) marries simulation modeling software such as STELLA to a powerful simulation execution environment. The SME facilitates the simultaneous execution of STELLA-like models for each grid cell associated with a raster GIS database (Maxwell and Costanza, 1997; Costanza and Ruth, 1998). The Patuxent model has been used for beta-testing of the Spatial Modeling Environment (SME) and Collaborative Modeling Environment (CME) (Voinov *et al*., 1999).

In addition to System Dynamics, Artificial Neural Networks (ANNs), Fuzzy Logic, and Genetic Algorithms are commonly used modeling technologies. ANNs have the ability to capture a relationship from given patterns and this makes them suitable for employment in the solution of large-scale complex problems, such as pattern recognition, nonlinear modeling, classification, association and control (Singh, 2006). Genetic Algorithms are search techniques employing the mechanics of natural selection and genetic. Srivastava *et al*. (2002) used genetic algorithms for watershed optimization of best management practices.

Watershed decision-making systems: There have been many studies of watershed decision-making support systems designed for various different purposes, such as water supply (e.g., Leavesley *et al*., 1996; Koutsoyiannis *et al*., 2003), soil conservation (e.g., Cox and Madramootoo, 1998), pollution (e.g., Djodjic *et al*., 2002), sustainable resource development (e.g., Smith *et al*., 2003), the impact of land-use change (e.g., Engel *et al*., 2003) and integrated watershed management (e.g., Miller *et al*., 2004). The lessons learned from these many watershed management initiatives indicate that in order to succeed, integrated watershed management must be participatory, adaptive and experimental, integrating all the relevant scientific knowledge/data and user-supplied information about the social, economic and environmental processes affecting natural resources at the watershed level (Steiguer *et al*., 2000).

Effective watershed management and planning requires the integration of knowledge, data, simulation models, and expert judgment to solve practical problems and provide a scientific basis for decision making at the watershed scale (National Research Council, 1999). A user-friendly Decision Support System (DSS) that would help different stakeholder groups to develop, understand and evaluate alternative watershed management strategies is needed. The DSS would consist of a suite of computer programs with components consisting of database management systems (DBMS), geographic information systems (GIS), simulation models, decision models, and easy-to-understand user interfaces (Miller *et al*., 2000). Effective management goes beyond the use of technology, and Heathcote (2009) has suggested that the integrated watershed management process involves several distinct steps: a) problem scoping and definition with decision-makers and professionals, b) assessment of legal and institutional concerns, c) consultation with stakeholders, d) inventory of the geology, soil, stream flow, groundwater, water quality, plant and animal communities, land use, and social and economic systems, f) development of management options, with associated costs, to solve the problem(s), g) assessment of management options, h) environmental and social impact assessment as required by law, i) selection of the best plan, j) obtaining financial support, and k) implementation and monitoring of the plan. She argued that if these are completed, then integrated watershed management is likely to be much more successful.

Social Development Systems

There has been increasing recognition that public participation can lead to better management of common resources. Benefits include a better-informed public, reduced conflict amongst different users, greater democracy through greater involvement of people in decision-making, more effective implementation of conservation measures and others (e.g., Ostrom, 1990; Ostrom *et al*., 1993; Dolsak and Ostrom, 2003), although they are only likely to be materialized if the participation process is carried all the way through to implementation (Margerum, 1999). Steiguer *et al*. (2000) state that watersheds are a highly desirable unit for planning because they are physical features, ubiquitous across the landscape and often serve as the geographic foundations for political jurisdictions. However, as planning units, watersheds can also transcend political boundaries. Prior to the 1970s, most watershed management focused on solving localized problems without taking into account the interrelationship between those problems and the biophysical, economic and social elements of the larger watershed system (Heathcote, 2009). In addition, during most of the mid- to late- 20th century, watershed management was, politically, a top-down planning process with national concerns pre-empting local concerns (National Research Council, 1999). Even at the local level, government desires to retain control over the decision-making process may have hindered the development of participatory decision-making in watershed management (Baviskar, 2004). Growing awareness of sustainable management, the development of democratic decision-making processes, the failure of existing attempts at watershed management planning, and increasing land-use conflicts at the scale of the watershed have all led to calls for wider public participation, and programs such as the European Water Framework Directive now place great emphasis on stakeholder and public participation in water management (Garin *et al*., 2002; Blomqvist, 2004; Jonsson, 2005).

As mentioned above, the advent of the Internet and World Wide Web has provided a good interface for participation in watershed planning and decision-making processes, but access to the Internet remains uneven. This is a fundamental problem – in developed countries, it is the older and less affluent segments of the population that may be excluded, whereas in the less-developed countries, lack of computer skills amongst the public, government controls on

Internet access, limited availability of computers and telephone connections and the presence of government officials who lack training in the use of web-based democratic processes may all hinder the effective introduction of the new technologies. These problems do not preclude public participation in watershed planning, they simply necessitate the adoption of different approaches (e.g., White and Runge, 1994; Porto, 1998; Horen, 2001).

Public participation is an important aspect of planning watershed management (Duram and Brown, 1999), but it needs to be conducted in an appropriate way to be successful (Konisky and Beierle, 2001; Webler and Tuler, 2001). A management plan requires the active involvement of all interested parties in developing the best approach to achieve its objectives. There are nine steps to the development of a general public participation plan: 1) identify the watershed problem(s); 2) set project goals and objectives; 3) define the study area and pilot projects to be completed; 4) identify objectives for public involvement; 5) identify the stakeholders and interest groups; 6) outline the benefits of and obstacles to public participation; 7) outline methods of public participation; 8) establish an action plan; and 9) put the plans into action. For example, in a study of the Havel Basin in northeast Germany (Jessel and Jacobs, 2005), detailed surveys were carried out to investigate the various interests of stakeholders. The interviews were used to identify the key problems in each of a number of areas in relation to water quality and quantity. The survey facilitated stakeholder engagement in catchment planning issues in the Havel River Basin. The information from the stakeholder interviews was used to determine the initial conditions for the land-use scenarios that were developed to demonstrate possible changes to land use that could result in improved water quality. In a second survey, the results of the scenarios and the hydrological modelling were presented to stakeholders. The consultation process identified the priorities of stakeholders that could then be taken into account when developing management options. In another example, there have been successful attempts to involve the public in integrated watershed management in Australia. Based on the very successful Landcare programme, communities across much of the country have now been involved in planning water resource use at regional scales, usually based on watersheds (Ewing, 1999; Curtis and Lockwood, 2000).

The participatory approach has been emphasized by Ffolliott et al. (2002), who has argued that "effective watershed management also requires responsible government agencies, locally-led partnerships, council, and corporations and other institutions to:

- Increase the awareness of all stakeholders about the importance of sustainable land use and the relationships that watershed management has built on, including the biophysical realities and the economic, social, and cultural factors that affect land use in watersheds.
- Identify all stakeholders, including the upstream and downstream stakeholders in watershed-use issues, and their perceptions and motivation about the issues.
- Classify agency and institutional jurisdiction over watershed management activities and improve the coordination between the agencies and institutions. This is especially significant because most countries have several agencies that have jurisdiction over uplands and over particular activities in those areas.
- Facilitate local management of upland natural resources by local residents in watersheds that are partially or entirely privately owned or controlled, and where agencies are not responsible for land, water, or other natural resource management.
- Distribute fairly the benefits and costs associated with upland natural resource use, and the application of watershed management practices between the upland and downstream land

users and other stakeholders.

- Assess the short- and long-term impacts of watershed management policies and activities as they evolve in order to encourage more effective watershed management. Feedback mechanisms (monitoring and evaluation programs) for this assessment must determine whether commodity-producing activities and the soil and water resources on which these activities depend can be sustained under the current policies – results from the assessment must be incorporated into future land-use policy." (pp. 131–132).

In summary, watershed management neither seeks nor needs a cure-all watershed model. The practices relating to resource use and management around the world do not depend solely on the physical and biological characteristics of watersheds, they also depend on a range of social elements. Watershed management needs to be a standard component in development programs that focus on water resources, forestry, agricultural and related land and resource use. To be effective, land-use administrators, water resource managers, foresters, and agriculturalists, along with professional watershed managers, must all be involved.

1.2 THE MIN RIVER WATERSHED

Given the fact that the manuscripts based on the Min River region as case studies, it is necessary to provide some background information about the study region. The Min River is located in south-eastern China, between 116°30' and 119°30' E and 25°20' and 28°25' N. It is the longest river in Fujian Province. The headwaters of the Min River are situated at an elevation of about 2115 m in the Wuyi Mountains in the north-western section of Fujian. Flowing generally east through the cities of Sanming, Nanping, and Fuzhou, the Min River Watershed covers an area of 60,992 km^2 and the river travels 2,872 km from source to sea. The main river has a length of 559 km (Fujian Chorography Compilation Committee 2002). The Min River Watershed (Figure 1–1) is an abundant water resource providing 130.05m^3 km^{-2} water, and with a water production coefficient of about 0.597, a surface runoff coefficient of around 53–60%, and an annual discharge of 6.21×10^{10} m^3 (Fujian Chorography Compilation Committee, 2002).

The Min River has played and continues to play an important role in the social, environmental and economic development of Fujian Province. Almost one third of Fujian's population of approximately 12 million people inhabits the watershed. It accounts for over half of the total agricultural production, two-thirds of the commercial logging, and 60% of the drinking water in the province. GDP is around 238.4 billion Yuan, 32% of provincial GDP and 41% of agricultural production (Table 1–1).

Figure 1-1. The research area, located in northern Fujian, China

Table 1-1. GDP of the Min River Watershed (2006). Units are in 100 million Yuan (1US$=8 Yuan). (Adapted from Fujian Province Bureau of Statistics, 2007).

	Gross Domestic	Primary	Secondary Industry			Tertiary	Per Capita GDP (Yuan)
Reach	Product	Industry	Subtotal	Industry	Construction	Industry	
Upper Reach	900	199	359	305	54.7	342	15,428
Middle Reach	149	51.5	46.1	38.3	7.81	51.3	10,716
Lower Reach	1336	122	613	527	86.2	601	28,569
Watershed total	2384	372	1018	870	149	994	20,044
Provincial total	7554	912	3725	3299	426	2918	22,692
% of province	32%	41%	27%	26%	35%	34%	88%

(Primary Industry is the term used to describe organizations that are involved in the development and production of raw materials, such as meat, grains, minerals and timber. It is used in various capacities within primary industry; Secondary Industry is involved in the manufacture of goods. Secondary industry often uses technology in the development and creation of goods; and Tertiary Industry is the field of industries that provide transportation or finance rather than manufacturing or extracting raw materials)

The Min River Watershed is used for generating hydroelectricity for urban and industrial use, irrigation, flood control, navigation, recreation, fishing and wildlife conservation. There are 29 large-scale hydropower stations in the watershed. A major construction project began in 1985, at ShuiKou (Figure 1–2), in Minqing County, to develop a power generation capacity of 1.4 million kilowatts annually. It is the biggest hydro-electric power plant in eastern China. The project was completed in 1996 and involved the resettlement of 67,000 people (Fujian Chorography Compilation Committee, 2002). In addition to generating power, the dam is expected to help control flooding in the Min River Watershed.

Figure 1-2. Fujian ShuiKou Dam and Shuikou Hydropower Station. (Photo: Guangyu Wang 2002).

The rapid population growth and economic development in the watershed appear to have caused serious local and regional environmental problems. Two of China’s largest pulp and paper mills release pollutants directly into the river; these pollutants are carried downstream to local communities that use the water to irrigate their farms and villages. Farmers, seeking the services associated with cities, have moved closer to the river, fuelling massive residential construction projects that put pressure on the area’s natural resources. The government has built transportation grids to accommodate this growth, but its apparent focus on economic development at the expense of environmental and social benefits seems to have resulted in severe over-crowding, together with air, water and soil pollution, water resource depletion, and soil loss.

These environmental and social stresses appear to have been caused by the competing claims of different stakeholders – local villagers who lived in the area before industrialization, forest collectives managing the lands that used to provide 70% of the pulpwood for mills, farmers needing river water for fish farms, the livestock husbandry, agriculture and township industries (pulp, plywood, food processing, shoes and toys). State agencies manage primarily at the county level, seemingly with little knowledge of or care for how their actions might influence the watershed downstream. Fujian Province’s legislative body – the Fujian People’s Standing Committee – has recently passed the Min River Protection Act, which established measures to mitigate the environmental and social impacts of industrialization on the river. The Fujian Environmental Protection Bureau (2005) issued the Min River Watershed Environmental Protection Plans in 2005; these are also supposed to ensure good management in the watershed. However, the Act and the Plans appear to lack any scientific foundation, and they fail to indicate how a more sustainable balance between the environmental, social and economic demands in the watershed will be achieved. Management tools are therefore needed that will allow the provincial legislature to monitor the health of the watershed as a whole, so that interagency cooperation can be improved, and competing claims on the land can be balanced.

1.3 OBJECTIVES

The concept of sustainable forest management was introduced into China after the United Nations Conference on Environment and Development in 1992 but, as shown below, there have been many problems associated with the adoption of western systems of management. While theory abounds, in reality it is extremely difficult to balance the sustainable use of limited natural resources with the high population densities and accelerated economic development that has been occurring over the past 10 years. In recent years, issues surrounding watershed management have caught the attention of both the government and the public. Several government departments and bureaus – such as Agriculture, Forestry, Water Conservation and Environmental Protection, and Oceans and Fisheries – have put great effort into a project called "Comprehensive Plans for Harnessing the Min River", which was formulated and issued by the Fujian Provincial Government. More than US$ 12 million was invested in the project annually between 1995 and 2005. Through the Min River Watershed Environmental Protection Plan, the Fujian Provincial Government is constructing 104 projects related to water pollution control facilities, waste management, headwater protection, clean development, recycling pilot projects, eco-agriculture model projects and environmental monitoring and scientific research, with a total investment of US$ 948 million (6.638 billion Yuan) between 2005 and 2010 (Fujian Environmental Protection Bureau, 2005).

As a result of the high level of available funding, a large number of research projects have been undertaken in the watershed. Zhao (1997) conducted hazard assessments for mountain torrents in the upper reaches of the Min River. He identified the triggering factors, propagating processes and spatial distribution of damage caused by mountain torrents. Zhang *et al*. (2000) analyzed floodwater distributions and the environmental fragility of the Min Valley. He argued that the degradation of the forest ecosystem had dramatically decreased water retention and soil conservation in the watershed over the last 30 years. Chen (2000) described the impacts of the industrial infrastructure and distribution on the environment in the Min River Watershed. As most of the heavy and metallurgical industries in the province are concentrated in the Nanping and Sanming areas, the upper reaches of the watershed account for more than 80% of water and air pollution in the watershed. He argued that future industrial developments should be regulated. Liang (2002) analyzed the forest resources in the watershed and the relationship between soil erosion and forest cover. The different vegetation types and quality in riparian areas had a major impact on rates of river sedimentation. He pointed out the importance of establishing riparian and soil protection forests in the area. Pang (2003) identified that intense precipitation combined with the unique landforms in the area, the malfunctioning of the reservoir water control system, and the over-cutting of forests, were the main causes of flooding in the Min River. He suggested that flooding could be avoided by increasing public awareness, coordinating between agencies, and developing a better system of watershed management. He also proposed increasing investment in eco-forestry development and management along the Min River.

Since 2005, research in the Min River Watershed has focused mainly on the control of water pollution (e.g., Liu, 2005; Zhu, 2005; Lan and Chen, 2006; Hong, 2005; Duan *et al*., 2007). The research has aimed at solving problems associated with non-point source pollution, pollution associated with livestock husbandry, and industrial pollution. The research has indicated that the rapid development of livestock has contributed to the recent increase in eutrophication, and has suggested that further control of the livestock industry is necessary. Hu and Li (2006a, 2006b), Li and Hu (2007) and Lin (2007) all focused on the development of payments for ecological services. They argued that the current determination of compensation for regional ecological benefits in the Min River Watershed lacked a sound scientific basis. They suggested that the government should use the cost-sharing method (the cost of ecological reconstruction) to determine rates of ecological compensation in the Min River Watershed. The research group led by Liu Jian (Fujian Agriculture and Forestry University) has started to look at forest fragmentation, forest productivity and stand volume estimation using Landsat images (Liu *et al*., 2006; Qi *et al*., 2006, Yu *et al*., 2006, 2007; Lai *et al*., 2007). However, current applications are still at the stage of improving classification accuracy and developing application techniques.

The limitation of most of these studies is that they are focused on only one or two subjects, such as flood routing, damage assessment, industrial pollution control, forest ecology, navigation, the irrigation system, or the ecological compensation system. Very few researchers have looked at the development of the watershed as a whole in relation to the mechanisms of watershed ecosystem degradation, the causes of the increase in natural disasters and social problems, or the measures needed to achieve sustainable development in the watershed. In particular, no studies have combined forest management with other social studies as part of an overall management process to achieve the goal of systematic development.

1.4 STRUCTURE OF THE THESIS

The research presented here appears to be the first time that a holistic approach to watershed management has been adopted in China. The aim is to try to understand the relationship between economic development and environmental protection in China during the period of social, political and economic transition that has occurred since the mid-1980s. In addition, I examine the impacts of national and regional development programs on watershed sustainability, and public perceptions of sustainable watershed development. The research involved a literature review, interviews with stakeholders, an analysis of existing watershed statistical data, and an analysis of satellite images with a view to examining the watershed's sustainability. This work has been placed into a broader context by examining current forest policies and their relation to environmental protection programs in China. Particular emphasis has been placed on the evaluation of forest policy and national programs to combat flooding.

The research used quantitative and qualitative methods from spatial and temporal spectra to examine human activities in the watershed, especially the interrelationships of stakeholders competing for the use of the watershed resources (Figure 1–3). The research examined two key developments – watershed management and forest management from three dimensions – physical topographic change (land use and land cover change), socioeconomic and environmental outcomes, and public perception.

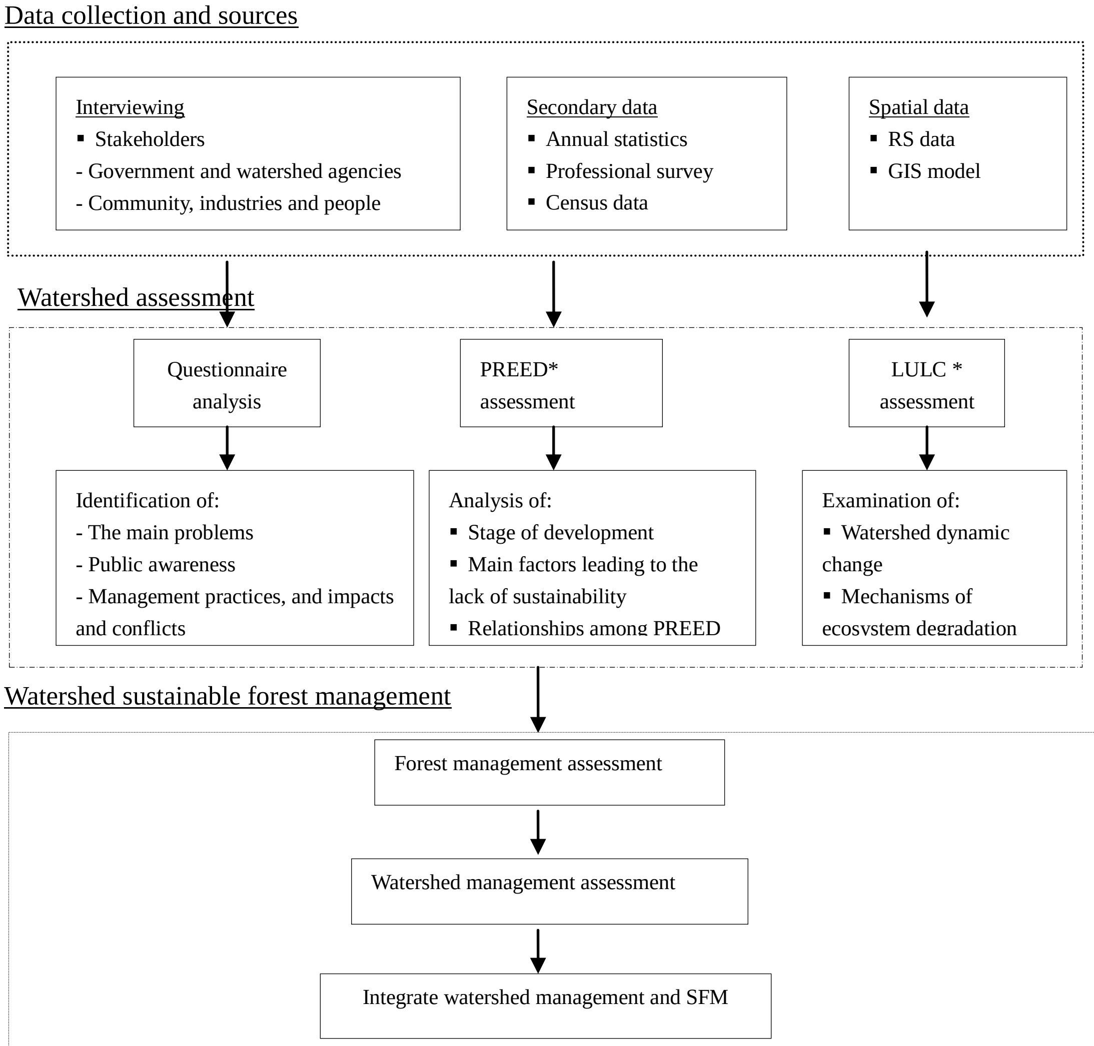

Figure 1-3. Flowchart for the research

(*PREED- population, resources, economy, environment and development; LULC- Land use and land cover; and SFM- Sustainable forest management)

The thesis is organized into two parts:

Part I examines Chinese nation-wide issues related to watershed management and forestry development over the last twenty years. This part, including this introductory chapter, contains reviews of the literature concerning several aspects of land management in China. Chapter 2 provides an overview of the development of watershed management in China, and the current priorities and issues facing watershed management in the country. Chapter 3 contains an overview of Chinese forest management issues, challenges, current government policy, and national key programs to improve forest ecosystems, rural livelihoods and wood supply, focusing on the period since 1998. Both these chapters focus exclusively on China. Assessing such developments in a broader, international context would have been interesting but was considered to be outside the scope of this thesis. Chapter 4 examines the effectiveness of the national key forestry programs and the impact of this on the environment and economic and rural development. Chapter 5 analyzes the current state of bamboo forest resources and management, and the roles of the bamboo forest industry in social development, economic growth and ecosystem protection. Over the past two decades, almost 500,000 hectares of bamboo forest have been established in the Min River Watershed, providing benefits to local communities, alleviating poverty and easing timber shortages. In this chapter, the main issues related to governance systems, local economic development and traditional management practices are also examined.

Part II uses the Min River as a case study to asses its land use change, soil erosion, public awareness and perception of watershed issues, and sustainability of the watershed over the last decade. Chapter 6 looks at changes in the patterns of land use in the Min River Watershed using Landsat imagery from 1986, 1990, 2000 and 2003. The mechanisms involved in land-use change over the past two decades are related to the economic development policy and population growth in the watershed, intensive land use and over-exploitation. The role of inappropriate development in the floods of recent years is examined. Chapter 7 examines the impact of infrastructure development on soil erosion: the impacts of 90 large-scale infrastructure projects undertaken between 1999 and 2004 are analysed. The potential for amelioration measures has been examined in a simulation experiment that compared soil erosion across different land covers for a period of one year following exposure. Chapter 8 looks at public awareness in relation to environmental protection in the Min River Watershed. Two major concerns about the watershed have been identified: pollution and flooding. The combination of traditional forestry practices combined with modern mechanisation is identified as being one of the primary problems leading to environmental degradation in the watershed. Chapter 9 uses the Sustainable Forest Management Certification Auditing Systems (SFMCAS) approach integrated with a Regional Sustainable Development Assessment (RSDA) to examine the state of sustainability of land and water resource use in the Min River Watershed.

Here, I should mention that there are three papers along with this research, namely, ‘Soil erosion associated with the establishment of Chinese Fir plantations in southeast China’ (Paper IX, submitted to *Forest Ecology and Management*); ‘Towards a new paradigm: the development of China’s forestry in the 21st century’ (Paper X © 2008 *International Forestry Review*); and ‘The need to cut China’s illegal timber imports’ (Paper XI © 2008 *Science*) have not been included in this thesis.

In the concluding chapter, I argue that watersheds are complex systems that require a balance between development and systematic management. The forest is a major factor in watershed ecosystems, and forest management can play a key role in mitigating or worsening the condition of the watershed ecosystem. Humans can both create and destroy modern civilizations, but they do not govern the natural forces of the planet, as the Sichuan earthquake disaster of May 2008 clearly showed. Humans should be responsible for their actions and their behaviour towards nature. They need to operate in harmony with nature and obey the laws of nature – the major conclusion from this research.

1.5 REFERENCES

Baviskar, A. 2004. Between micro-politics and administrative imperatives: Decentralisation and the watershed mission in Madhya Pradesh, India. *European Journal of Development Research* 16 (1), 26–40.

Barry, J.M. 1997. *Rising Tide.* Simon & Schuster. New York.

Blomquist, W. and Schlager, E. 2005. Political pitfalls of integrated watershed management. *Society and Natural Resources* 18, 101–117.

Brooks, K.N. and Eckman, K. 2000. Global Perspective of Watershed Management, UCSON, Arizona, USA. USDA Forest Service.

Brooks, K.N., Gregersen, H.M., Ffolliott, P.F., and Tejwani, K.G. 1992. Watershed management: a key to sustainability. In: Sharma, N.P., ed., Managing the world's forests. Dubuque, IO: Kendall/Hunt Publishing Company, pp. 455–487.

Brooks, K.N., Ffolloit, P.F., Gregersen, H.M, and DeBano, L.F. 2003. *Hydrology and the Management of Watersheds*. Ames, Iowa State Press.

Calder, I.R. 1999.*The blue revolution: land use and integrated water resources management*. London, Earthscan Publications Ltd.

Chandra, S. 1990. *Hydrology in Ancient India*. National Institute of Hydrology, Rookee, India, 106 pp.

Chen, C.M. 2000. The impact of the industrial structure and distribution on environment around Min River Watershed. *Journal of Fujian Geography* 15 (1), 14–17.

Chen, Y.D. 2004. Watershed modeling: Where are we heading? *Environmental Informatics Archives* 2, 132–139.

Costanza, R. and Ruth, M. 1998. Using dynamic modeling to scope environmental problems and build consensus. *Environmental Management* 22 (2), 183–195.

Cox, C. and Madramootoo, C. 1998. Application of geographic information systems in watershed management planning in St. Lucia. *Computers and Electronics in Agriculture* 20 (3), 229–250.

Curtis, A. and Lockwood, M. 2000. Landcare and catchment management in Australia: lessons for state-sponsored community participation. *Society and Natural Resources* 13 (1), 61–73.

Davenport, T. E. 2003. *The Watershed Project Management Guide.* Lewis Publishers, Boca Raton, 296 pp.

Davies, J.-M. and Mazumder, A. 2003. Health and environmental policy issues in Canada: the role of watershed management in sustaining clean drinking water quality at surface sources. *Journal of Environmental Management* 68 (3), 273–286.

Djodjic, F., Montas, H., Shirmohammadi, A., Bergström, L. and Ulén, B. 2002. A Decision Support System for phosphorus management at a watershed scale. *Journal of Environmental Quality* 31, 937–945.

Dolsak, N. and Ostrom, E. (eds.) 2003. *The Commons in the new millennium: challenges and adaptation*. MIT Press, Cambridge, Mass. 369 pp.

Donigian, A.S. Jr. and Imhoff, J. 2006. History and Evolution of watershed modeling derived from the Stanford Watershed Model. In: Singh, V.P. and Frevert, D.K. (eds.) *Watershed Models.* CRC Press, Boca Raton, pp. 21–45.

Dortiganc, E.J. 1967. *Forest water yield management opportunities.* National Science Foundation Advanced Seminar, Pennsylvania State University. Pergamon Press.

Duan, Y., Zhang, Y.Z., Li, Y. and Niu, Z. 2007. Pollution load and environmental risk assessment of livestock manure in the Min River Valley. *Journal of Ecological and Rural Environment* 23 (3), 55–59.

Duda, P.B., Kittle, J.L. Jr., Donigian, A.S. Jr., and Kinerson, R.S. 2006. Better assessment science integrating point and nonpoint sources (BASINS). In: Singh, V.P. and Frevert, D.K. (eds.) *Watershed Models.* CRC Press, Boca Raton, pp. 273–289.

Duram, L.A. and Brown, K.G. 1999. Assessing public participation in U.S. watershed planning initiatives. *Society and Natural Resources* 12 (5), 455–467.

Engel, B.A., Choi, J.-Y., Harbor, J. and Pandey, S. 2003. Web-based DSS for hydrologic impact evaluation of small watershed land use changes. *Computers and Electronics in Agriculture* 39 (3), 241–249.

Ewing, S. 1999. Landcare and community-led watershed management in Victoria, Australia. *Journal of the American Water Resources Association* 35, 663–673.

FAO and CIFOR 2005. Forests and Floods: Drowning in Fiction or Thriving in Facts? RAP Publication 2005/03—Forest Perspectives 2. UN Food and Agriculture Organization and Center for International Forestry Research. Bangkok, Thailand.

Ffolliott, P.F. Baker, M. B., Jr., Edminster, C. B., Dillon, M. C., Mora, K. L.2002. *Land stewardship through watershed management: perspectives for the 21st century*. Springer: New York.

Fujian Chorography Compilation Committee 2002. *Fujian Chorography.* Fangzi Publishing: Fuzhou.

Fujian Environmental Protection Bureau 2005. *The Min River Watershed Environmental Protection Plan*. Fujian Environmental Protection Bureau.

Fujian Provincial Bureau of Statistics. *Fujian Statistical Yearbook.* 2007. Fujian Provincial Bureau of Statistics: Fuzhou.

Garin, P., Rinaudo, J.P. and Ruhlmann, J. 2002. Linking expert evaluations with public consultation to design water policy at the watershed level. *Water Science and Technology* 46 (6–7), 263–271.

Gearey, M. and Jeffrey, P. 2006. Concepts of legitimacy within the context of adaptive water management strategies. *Ecological Economics* 60 (1), 129–137.

Heathcote, I.W. 1998. *Integrated Watershed Management – principles and practice.* Wiley: New York.

Heathcote, I.W. 2009. *Integrated Watershed Management – principles and practice.* 2nd Edition. Wiley: New York.

Hong, H. 2005. The Min River water pollution and countermeasures. *Recommendation and Consultation* l (2), 48–50.

Hong, W. 2000. *Study on Forestry Ecosystem in the Min River.* Xiamen University Press. 2001: Ximen.

Horen, V.B. 2001. Developing community-based watershed management in Greater São Paulo: the case of Santo André. *Environment and Urbanization* 13 (1), 209–222.

Hu, Y. and Li, Y. 2006a. The establishment of the inter-catchment's ecological compensation system. *Journal of Fujian Normal University* 141, 53–58.

Hu, Y. and Li, J. 2006b. The ecological compensation and calculation method for Min River Watershed. *Development Research* 11, 95–97.

Jessel, B., and Jacobs, J. 2005. Land use scenario development and stakeholder involvement as tools for watershed management within the Havel River Basin. *Limnologica* (35), 220–233.

Jonsson, A. 2005. Public participation in water resources management: Stakeholder voices on degree, scale, potential, and methods in future water management. *Ambio* 34 (7), 405–500.

Koutsoyiannis, D., Karavokiros, G., Efstratiadis, A., Mamassis, N., Koukouvinos, A. and Christofides, A. 2003. A decision support system for the management of the water resource system of Athens. *Physics and Chemistry of the Earth*, Parts A/B/C, 28 (14–15), 599–609.

Konisky, D.M. and Beierle, T.C. 2001. Innovations in public participation and environmental decision making: Examples from the Great Lakes Region. *Society and Natural Resources* 14 (9), 815–826.

Krairapanond, N. and Atkinson, A. 1998. Watershed management in Thailand: Concepts, problems and implementation. *Research and Management* 14, 485–498.

Lai, R., Liu, J., Yu, K. and Wu, L. 2007. Spatial pattern and variance of forest productivity based on remote sensing and GIS. *Journal of Fujian College of Forestry* 27 (4), 360–364.

Lan, L. and Chen, X. 2006. Problem analysis of water environment in the low Min River. *Environmental Science and Management* 31 (7), 126–134.

Leavesley, G.H., Markstrom, S.L., Brewer, M.S. and Viger, R.J. 1996. The Modular Modeling System (MMS) – the physical process modeling component of a database-centered decision support system for water and power management. *Water, Air and Soil Pollution* 90 (1–2), 303–311.

Li, Y. and Hu, Y. 2007. Regional ecological benefit compensation standard in Min River Watershed. *Research of Agricultural Modernization* 28 (3), 327–329.

Liang, W.H. 2002. The Min River Watershed eco-forest protection and construction. *Journal of Eastern China Forest Management* 16 (1), 39–42.

Lin, L. 2007. Further improvement for ecological compensation system in Min River Watershed. *Development Research* 11, 32–33.

Liu, J., Yu, K., Qi, X. and Huang, W. 2006. Forest land cover type classification based on expert system. *Journal of Fujian Agriculture and Forestry University* 35 (1), 42–46.

Liu, S. 2005. Discussion of eutrophication in upper reach of the Min River. *Fujian Analysis and Testing* 14(2), 2185–2190.

Margerum, R.D. 1999. Getting past yes: From capital creation to action. *Journal of the American Planning Association* 65 (2), 181–192.

Maxwell, T. and Costanza, R. 1997. An open geographic modeling environment. *Simulation* 68 (3), 175–185.

Mcginnis, M.V., Woolley, J. and Gamman, J. 1999. Bioregional conflict resolution: rebuilding community in watershed planning and organizing. *Environmental Management* 24 (1), 1–12.

Miller, R. Guertin, D.P. and Heilman, P. 2000. An Internet-based Spatial Decision support system for support system for rangeland watershed management. USDA Agricultural Research Services, pp. 725–730. http://www.tucson.ars.ag.gov/ICRW/Proceedings/Miller%20Ryan.pdf

Miller, R.C., Guertin, D.P. and Heilman, P. 2004. Information technology in watershed management decision making. *Journal of the American Water Resources Association* 40, 347–357.

Montgomery, D.R., Grant, G.E. and Sullivan, K. 1995. Watershed analysis as a framework for implementing ecosystem management. *Water Resources Bulletin* 31, 369–386.

Naiman, R.J., Bilby, R.E. and Bisson, P.A. 2000. Riparian ecology and management in the Pacific Coastal Rain Forest. *BioScience* 50 (11), 996–1011.

National Research Council (NRC) and Committee on Watershed Management 1999. *New Strategies for America's Watersheds.* National Academy Press, Washington, D.C.

Pang, M.Z. 2003. The cause of flooding in Min River and protection measure. *Journal of Eastern China Forest Management* 17(2), 35–39.

Powell, J.W. 1890. Institutions for arid lands. *The Century* 40, 111–116.

Qi, X., Liu, J., Yu, K., Huang, W., Wang, W. and Chen M. 2006. Analysis on forest landscape pattern on Min River Watershed based on RS and GIS. *Journal of Forestry College of Forestry* 26(1), 36–40.

Ostrom, E. 1990. *Governing of the Commons – The evolution of institutions for collective action*.

Cambridge University Press, Cambridge. 280 pp.
Ostrom, E., Schroeder, L. and Wynne, S. 1993. *Institutional incentives and sutainable development. Infrastructure policies in perspective.* Westview Press, Boulder, Colorado. 266 pp.
Porto, M. 1998. The Brazilian Water Law: a new level of participation and decision making. *Water Resources Development* 14 (2), 175–182.
Samra, J.S. and Eswaran, H. 1997. Challenges in ecosystem management in a management in a watershed context in Asia. In: Lal, R. (Ed.), *Integrated Watershed Management in the Global Ecosystem*. Boca Raton, CPC Press, pp. 19–32.
Smith, D.W., Prepas, E.E., Putz, G., Burke, J.M., Meyer, W.L. and Whitson, I. 2003. The Forest Watershed and Riparian Disturbance study: a multi-discipline initiative to evaluate and manage watershed disturbance on the Boreal Plain of Canada. *Journal of Environmental Engineering Science* 2, S1–S13.
Singh, V.P. 1995. *Computer Models of Watershed Hydrology.* Water Resources Publications, LLC: Highlands Ranch, USA.
Singh, V.P. and Frevert. 2002. *Mathematical Models of Large Watershed Hydrology*. Water Resources Publications, LLC: Highlands Ranch, USA.
Singh, V.P. and Frevert. 2002. *Mathematical Models of Small Watershed Hydrology and Application.* Water Resources Publications, LLC: Highlands Ranch, USA.
Singh, V.P. and Frevert, D.K. 2006. *Watershed Models.* Boca Raton: Taylor and Francis Group.
Srivastava, P., Hamlet, J.M., Robillard, P.D., and Day, R.L. 2002. Watershed optimization of best management practices using ANNAGNPS and a genetic algorithm. *Water Resources Research* 38(3), 1–14.
Steiguer, de J.E., Duberstein, J. and Lopes, V. 2000. The Analytic Hierarchy Process as a means for Integrated Watershed Management. USDA Agricultural Research Services, pp. 763–744. www.tucson.ars.ag.gov/icrw/Proceedings/Steiguer.pdf
Steins, N.A., and Edwards, V.M. 1999. Platforms for collective action in multiple-use common-pool resources. *Agriculture and Human Values* 16, 241–255.
Tennyson, L. 2003. Review and assessment of watershed management strategies and approaches. In the conference proceeding of the Asian Regional Workshop. *Preparing for the Next Generation of Watershed Management Programs and Projects.* Kathmandu, Nepal 11–13 September 2003.
Tim, U.S. 2003. Application of GIS technology in watershed-based management and decision making. *Watershed Update* 1 (5), 1–6.
Voinov, A., Costanza, R., Wainger, L., Boumans, R., Villa, F., Maxwell, T. and Voinov, H. 1999. Patuxent landscape model: integrated ecological economic modeling of a watershed. *Environmental Modeling and Software* 14, 473–491.
Wang, G.Y., Innes, J.L., Lei, J.F., Dai, S.Y. and Wu, S. 2007. China's Forestry Reform. *Science* 318, 1556–2557.
Webler, T. and Tuler, S. 2001. Public participation in watershed management planning: Views on process from people in the field. *Human Ecology Review* 8 (2), 29–39.
Westervelt, J. (2003). *Simulation Modeling for Watershed Management.* New York, Springer.
White, T.A. and Runge, C.F. 1994. Common property and collective action: Lessons learnt from cooperative watershed management in Haiti. *Economic Development and Cultural Change* 43 (1), 1–41.
WMO/UNESCO 1969. *International Glossary of Hydrology*: 138pp.
Wright, M.L. and Padgitt, S. 2005. Selecting social-economic metrics for watershed management. *Environmental Monitoring and Assessment* 103, 83–98.
Yang, G.S., Yu, X.P., Li, H.P. and Gao J.F. 2006. *Introduction to Integrated Watershed*

Management. Science Press: Beijing. 238pp.
Yu, K., Lin, F., Liu, J. and Qi, X. 2006. Study on estimating model of *Pinus massoniana* stand volume in Min River Watershed based on RS technologies. *Journal of Fujian Forestry Science and Technology* 33 (1), 16–23.
Yu, K., Liu, J., Qi, X. and Huang, C. 2007. Dynamical monitoring on the ecological forest stand volume in the Min Watershed based on RS technology. *Journal of Fujian Agriculture and Forestry University* 36 (5), 481–485.
Zhang, G., Chen, R., Zeng, J. and Lin, W. 2000. A study on flooding and fragility of environment in the Min Valley. *Journal of Soil and Water Conservation* 20 (4), 51–55.
Zhao, S.P. 1997. Hazard assessment for mountain torrents on the upper reach area of Min River. *Geographical Research* 16 (1), 98–103.
Zhu, X.D. 2005. Non-point source pollution control and countermeasures of the Min River Watershed. *Subtropical Soil and Water Conservation* 17 (4), 55–57.

2 WATERSHED MANAGEMENT IN CHINA: PAST, PRESENT AND FUTURE DEVELOPMENT[1]

2.1 INTRODUCTION

Watershed management, an ancient concept defined in Vedic text from India dating from 1,000 BC (Chandra, 1990), can be traced back to the time of the Xia Dynasty (2100 B.C.) in China (e.g., Zheng, 2004; Chen, 2007). Today, sustainable development practices endow watershed management with a broader concept and new meaning, new methods and new approaches. Watershed management in China has emerged as a holistic approach to managing the regional biological, physical and social aspects. The rapid development of the Chinese economy over the past thirty years, which has taken priority over environmental protection, has resulted in large-scale ecosystem degradation and water pollution, both of which are greatly jeopardizing the social structure, economic development and living conditions in China (Yang *et al.*, 2006). Current watershed management mechanisms in China do not deal effectively with watershed problems (CAS Sustainable Development Research Group, 2007). In this review of the development of China's watershed management, and supported by case studies of the three most influential watershed management programs in China, I suggest that future watershed management in China should involve: 1) the improvement of its legal system and law enforcement; 2) the construction of an appropriate management structure, complete with inter-agency working mechanisms; 3) the development of a structure that could better balance the interests of all stakeholders; 4) an integrated approach to watershed planning; 5) greater stakeholder participation; 6) better information exchange, and 7) better and more comprehensive public education.

2.2 HISTORY OF WATERSHED MANAGEMENT IN CHINA

Watershed management has been evident throughout Chinese civilization and can be traced back to about 2000 BC (Zheng, 2004; Chen, 2007). The earliest planned watershed development in human history occurred in China during the Xia Dynasty (2100 BC). Dayu, a Chinese hydrological engineer, worked for 13 years along the Yellow River and successfully controlled the flooding that was prevalent at the time. By the Shang Dynasty (1600 to 1046 BC), people in the Yellow river area were using the 'furrow approach', an early form of strip cropping that conserves soil nutrients and water (Wang, 2003). Three thousand years ago, historical records reveal that people in XiZhou were practising water storage, managing discharge and using irrigation (Tan, 2005).

Some of the earliest major developments occurred in the Zhou Dynasty (1046 to 256 BC), and affected the Yellow River watershed. Around 256 BC, Li Bing led the Dujiangyan Irrigation

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Project on the Minjiang River, a tributary of the Yangtze River. This was one of largest scale irrigation projects in Chinese history, and still provides benefits to the region. In particular, it drastically reduced the incidence of flooding on the Chengdu Plain (Tan, 2005). In 246 BC, Zheng Guo, a hydrologist, launched a program introducing water from the Guangzhong watershed to Loushui, 300 km east, and irrigating 40,000 ha. of farmland (Wei, 2005). The Zhengbai Canal System, which was responsible for the irrigation of about a third of the farmland in China at that time, was subsequently extended during later dynasties (Anonymous, 2007).

After the unification of China in 221 BC by the Emporer Qin Shi Huangdi, the first Central Government agency for water management was established, with the Emperor appointing water officers to take charge of watershed management. An example of one of the major projects undertaken by Qin Shi Huangdi is the Ling Canal System, which connected the Xian River Watershed in Hunan province to the Li River Watershed in Guangxi province. It was completed in 214 BC. The canal system connects the Pearl and Yangtze Rivers, linking two of the largest river systems in China.

A second large-scale development occurred in the Sui (581–617 AD) and Tang (618–907 AD) Dynasties. This involved the Yangtze River watershed and southeast China. The best-known project is the Jing–Hang Giant Canal System (also known as the Beijing–Hangzhou Grand Canal**)**, at 1770 km the longest water system ever constructed in China. Throughout the period, the government focused on physical engineering projects, including dams, dykes, and levée construction in the delta of the Yangtze River, with the primary objective of creating good conditions for agriculture and waterways for transportation (Zheng, 2006).

A third large-scale development occurred in the Ming (1368–1644 AD) and Qing (1644–1911 AD) Dynasties, when watershed development was largely focused on mountain protection. The hydrologist Xu Zhenming (1573–1620) pointed out that “prior to harnessing the river, the mountain should be protected”, thereby initiating important work in headwater regions. Kangxi (1654–1722), an emperor of Qing Dynasty, was also a hydrologist. He considered that harnessing water resources was one of the three key factors in governing the country. He increased the national budget for water and watershed management by a factor of 10 and was personally involved in the planning of several river projects. He paid six visits to the Yellow River to investigate watershed development and flood control. By 1820, 30% of the area cultivated for rice was irrigated, compared to only 3.5% in India in 1850 (CAS Sustainable Development Strategic Research Group, 2007). These developments contributed to the long period of prosperity enjoyed by China in the second half of the 17th and early 18th century under the rule of the Emperor Kangxi (Gu, 2006).

In the late 19th and early 20th centuries, China suffered greatly from the two World Wars and a major Civil War. Chinese social, economic and environmental development was greatly set back. Three human-induced disasters in the 20th century, namely the Wars, the ‘Great Leap Forward’, and the ‘Cultural Revolution’, led to China becoming one of the most backward and disadvantaged countries in the world (Yang *et al*., 2006).. Having supported millions of people for thousands years, the Yellow River Basin and the Loess Plateau became some of the most degraded land on the planet, and the origin of the soil erosion, desertification, and sandstorms that have seriously threatened the lower reaches of the Yellow River Basin and eastern China (e.g., Yang and Liu, 1992; Ren and Zhu, 1994; Kong *et al*., 2002; Li *et al*., 2003; Feng *et al*., 2005; Ma *et al*., 2005).

The recent rapid development of the economy without adequate environmental protection over the past thirty years has created a number of problems, including unregulated infrastructure development, over-exploitation of forest resources, and large volumes of untreated sewage being directly released into rivers and other water bodies. The result has been large-scale ecosystem degradation and water pollution (Economy, 2004), both of which are greatly jeopardizing the social structure, economic development and living conditions in China. According to Pan Yue, Deputy Minister of the Environmental Protection Agency of China, "300 million rural residents drink unsafe water; and one-fifth of China's major cities fail to meet the country's minimum standards for drinking water" (Pan, 2006).

2.3 MODERN WATERSHED MANAGEMENT IN CHINA

Over the last thirty years, as a result of economic development and social progress, along with the devastation of the environment (e.g., Smil, 1993; Economy, 2004; Gleick, 2008), watershed management has received increasing attention from various levels of government, the public and local communities in China. The development of hydropower and irrigation to meet the need for industry and agricultural development, the protection and utilization of forest resources to meet the demand for wood and water conservation, and the security of drinking water and discharge of untreated waste appear to have become the drivers in China's watershed development. The large-scale flooding that has occurred throughout China since 1992 (particularly in 1998) became the turning point in China's watershed management and forest protection (Wei *et al*., 2008). The Administration Committees of the Yellow, Yangtze, Zhu, Hai, and Songhua Rivers and Tai Lake have been resumed or established (He *et al*., 2001). A Water Law was passed in 1988, and amended in 2002. Several developments are of particular interest. Compared to the original Water Law, and in order to fulfill China's commitments to international agreements and China's Agenda 21, several key points have been stressed in the amendment, including: 1) unified management of water resources, and the need for integrated watershed management systems and clarification of the legal status of watershed management administrative institutions; 2) implementation of water use rights and permits through the introduction of market mechanisms into water management; 3) an emphasis on the importance of watershed development planning, water relocation regulation, and water use efficiency and conservation; and 4) an emphasis on balancing the development of water utilization and economic growth with environmental protection and protection of water resources from pollution. The weaknesses of the new Water Law include: 1) Lack of provision for public participation in the protection of individuals' rights to learn about and act upon watershed issues, and 2) the lack of an ecological compensation mechanism, even though the new law has laid out water use charges. There is no provision for water conservation. Although the water legislation framework defined in Caracas and Mar del Plata (International Association for Water Law, 1976; Heathcote, 1998, Biswas, 2004, Salman and Bradlow, 2006; Heathcote, 2009) has not been fully adopted in the 2002 Water Law, China is now considering and working towards a comprehensive system of water law. The system will include sub-laws on water pollution control, flood prevention, water and soil conservation, water utilization, transportation, energy development, wetland management, lake protection and watershed management.

There has been a change from single-purpose water management to a more holistic form of watershed management, involving comprehensive planning and integrated management (e.g., Wang, 1999; Economy, 2004; Cannon, 2006). The Central Government seems to have recognized the watershed as an important unit for the development of water and soil resources planning and for the management and utilization of natural resources. As a result, by 1997, management plans for the seven main river watersheds had been completed and implemented. The first stage of the plans was completed in 2003, and included large-scale water control and hydroelectric power projects such as the Long Yang Gorge, San Men Gorge, Dan Jiang Kou, Xingan River, Shuifen, Miyuan, Guanting, Pan Jiankou, and Meishan (Wang, 2003). The Three Gorges Project along the Yangtze River and the Xiaolangdi Multipurpose Project along the Yellow River are symbolic projects that are intended to demonstrate China's arrival in the modern world. Less well-publicized are the more than 10,000 watersheds that have been implementing watershed control and development plans, involving a total area of 40 million ha. and the protection of 22 million ha. of land from soil and water erosion (Wang, 2003).

A number of projects have been developed with the goal of promoting regional development. In 1983, the State Council identified eight national key areas for protection against soil and water erosion, with a further six areas, and two reservoirs – Miyuan and Pan Jiankou – being added in 1989. In total, the program involved 43 million ha. across 15 provinces and 245 counties (Wang, 2003). At the same time as this federal exercise, provincial and county governments were identifying key local restoration programs and pilot projects, and these have greatly promoted the use of sustainable watershed management approaches in the development of local watersheds. After the 100-year floods of 1998, a ban was placed on the logging of all natural forests in the headwaters of rivers (Wang *et al*., 2007).

At the same time as the introduction of the logging bans, six headwater forest conservation programs were introduced to protect and afforest 20.1 million ha, involving an investment of US$ 11.8 billion. According to the State Forestry Administration, the Natural Forest Protection Program (NFPP) started officially in 2000 (with the planned period of operation being from 2000 to 2010), and involved 17 provinces. It aims is to reduce annual wood production from natural forests by 20 million m^3 through a logging ban, a reduction of harvesting on sensitive sites, and the relocation of 740,000 workers made redundant by the ban. The Conversion of Cropland to Forest Program (CCFP) plans to invest more than US$ 60.5 billion in planting trees and restoring grasslands in the 12 western provinces of China by 2010. It aims to restore 22 million ha. of eroded land and 25 million ha. of dry lands, reducing the release of sediment into the Yangtze and Yellow Rivers by 260 million tonnes annually. Surveys indicate that 4.98 million ha. of forest have been planted as part of the NFPP Program ain the period 2000–2006, and 18.7 million ha. have been planted in the CCFP program over the same period (State Forestry Administration, 2007).

Accompanying the development of more holistic approaches to watershed management, there has been a remarkable philosophical shift from government control to the development of public responsibility (Wang, 1999; CAS Sustainable Development Strategic Research Group, 2007). With the implementation of the Household Responsibility Systems (Lin, 1986) by the central government, local farmers have become a core force in watershed management. The government, by ceding ownership and management rights to farmers, has generated enthusiasm for watershed management, with different management models being created to meet specific local conditions. This change has also resulted in much greater public participation and stakeholder involvement in watershed planning and decision-making (Yang *et al*., 2006). Success stories include the use of a public-participatory approach to reduce pollution in the Yuqiao Reservoir, the source of drinking water for the City of Tianjing in China (Jones *et al*., 2002), and a Sino-German cooperation project for the sustainable development of mountain areas in Jiangxi Province (MLR, 2006). In the latter project, a participatory approach to rural development was introduced, with the aim of conducting land-use planning, disseminating methods of natural resources management, strengthening the development of a farmers' self-help organization, and providing financial micro-credits to farming households.

There has been a clear evolution from a very passive approach to watershed management to one that is much more active. Since implementing the Household Responsibility Systems, watershed management has become a mechanism for poverty alleviation (e.g., Wang, 1999; Li, 2003; Upadhyay, 2003). To enable local farmers to gain material benefits from watershed management, the various levels of government have paid great attention to the integration of watershed protection and rural development. The new concept of watershed management that has been promulgated is to combine long-term benefits with short-term outcomes, integrating environmental values with economic profits, and coalescing soil and water protection with poverty reduction (CCICED, 2005). Pilot studies have been undertaken in national key protection areas, and the outcomes seem promising (Yang *et al*., 2006). The development of bamboo forests, hay meadows, traditional medicinal herbs and non-timber forests in fragile areas are successful models for this new approach (State Forestry Administration, 2006).

National laws, provincial by-laws and soil and water regulations have been developed. In 1982, the State Council of China issued the Soil and Water Conservation Regulation, and this has been accompanied by detailed provincial regulations in every province. In 1991, the Law of the People's Republic of China on Water and Soil Conservation was promulgated, together with the Water Law, Flood Control Law, Forest Law, Agricultural Law, Fishery Law, Law on Protection of Wildlife, Land Management Law, Grassland Law, Mineral Resources Exploitation Law and many others. These apply at national, provincial and local levels, and the legislation means that China can be considered to have developed the necessary legislative framework to address watershed management issues in the country.

Overall, watershed management has been becoming a core aspect of environmental reconstruction efforts in China. This is confirmed by China's Agenda 21 and the National Ecological Environmental Construction Plans (1996–2050), in which the government has identified watershed management as an important component of environmental reconstruction and sustainable development.

2.4 CURRENT PRIORITIES AND ISSUES FOR WATERSHED MANAGEMENT IN CHINA

Since the 1980s, China has been experiencing unprecedented economic development and social transition. As a result of rapid urbanization and industrialization, the conflict between population growth, resource exploitation, and ecosystem protection has become acute. The consequence is an environmental crisis and deficit in natural resources that have raised the importance of water issues and watershed management. These represent important, complex and challenging issues and are discussed below.

2.4.1 Water resource deficit and reallocation

Water shortages are a key element for China's social and economic development and for environmental protection. Currently, per capita water consumption in China is only 25% of the world average, and 2% of that in Canada. In China, 76% of cities now face water shortages (CAS Sustainable Development Strategic Research Group, 2007). The allocation of water resources has been an important issue throughout China's history. Water use is the main source of conflict between upstream and downstream users, and between different economic sectors relying on water (e.g., UN/World Water Assessment Programme, 2003; Grover, 2006; Cannon, 2006, and Gleick, 2008). The allocation of water has far-reaching implications for water supply, water transportation, fish resources, tourism, land degradation, the depletion of groundwater and pollution, and can even develop into international disputes. There are numerous water reallocation projects underway in China. The most influential project – the South-to-North Water Transfer Project – was launched on December, 27, 2002. The project has proposed that by 2050, around 45 billion m^3 of water a year will be transferred annually from the Yangtze River through the Eastern, Central and Western Canals to the Yellow River, Huai River and Hai River basin, where there are serious water deficits (e.g., Gleick, 2008). The estimated cost is $60 billion (US Embassy, 2003; Zhu, 2006). Many issues, such as the environmental impact and the resettlement of locals, together with numerous organizational and financial issues, remain unresolved.

2.4.2 Floods and droughts

In China, most flood control facilities have a capacity to protect against floods with a 20–50 year return period (CAS Sustainable Development Strategic Research Group, 2007). However, the losses attributable to floods have been increasing. In the 1990s, the average annual losses caused by flooding were about US$ 15 billion (110 billion RMB), about 1.8% of the annual GDP. In particularly bad years, such as 1991, 1994, 1996 and 1998, the costs were equivalent to about 3–4% of GDP. These figures compare with 0.1% and 0.3%, respectively, in the USA and Japan (China's Water Management Modernization Research Group (CWMMRG), 2004). The CWMMRG (2002) study suggested that the national economic capacity of China can only bear losses equivalent to 0.6%. The economic losses, combined with an annual average death total of 1537 people, indicate the need for the immediate introduction of steps to reduce the extent of flooding. The losses caused by droughts vary from year to year, but are equally great. In the 1990s, the average annual loss was equivalent to 1.1% of GDP, and in 2000, the figure was 2.5%. A target of limiting average annual drought losses to 0.8% of GDP has now been set (Zhou, 2007).

2.4.3 Pollution and the degradation of ecosystems

Population expansion, the rapid development of the economy and environmental degradation are closely linked in China. Water pollution accidents have received frequent attention from the mainstream media – as with the Tuo (Sichuan) River in 2004, and the Songhua (Heilongjiang), Bei (Guangdong), and Zhi (Hunnan) Rivers in 2005. Pollution-related GDP losses reached 3.05% of the total GDP in 2004 (State Environmental Protection Administration and the National Bureau of Statistics of China, 2006; Qiu, 2007). The environmental pollution costs include costs of 10 items, such as health, agricultural and materials losses caused by air pollution; health, industrial and agricultural production losses, and water shortage caused by water pollution; economic loss caused by land occupation of solid wastes and etc.. Environmental problems, and in particular the large numbers of natural disasters since the 1990s, have forced national, provincial and city governments to acknowledge the importance of environmental restoration and rehabilitation (Economy, 2004; An et al., 2007). The most obvious steps in the mitigation of the environmental degradation include the headwater logging bans, the western development program, and the six national forestry programs (Wang et al., 2007). However, even with these steps, frequent reports in the media indicate that the pressure for economic development is forcing provincial and city governments to proceed with developments that are clearly destined to create environmental problems. The increasing divergence between the environmental protection aims of the Central Government and the practices of local governments, as exemplified by the debate over the introduction of a green GDP, is likely to be a source of increasing conflict in the future, and is discussed below.

2.4.4 Institutional issues

In China, watershed management systems overlap greatly. At the level of the central government, the Ministry of Water Resources Management (MoWRM) is responsible for basin management and, as a result, basin administration committees have been established for each of the seven main rivers. These oversee flood mitigation, sediment and drought control, water pollution along the sub-basin borders, water resources programs and other related affairs. However, at the provincial and local level, local Departments of Water Resources are responsible for within-jurisdiction development. These local departments have been playing a dominant role in water resources management, while the federal river basin committees have failed to fulfill their anticipated roles (He and Chen, 2001).

He and Chen (2001) have also drawn attention to the overlap in responsibilities between the MoWRM, the State Environmental Protection Agency (which is responsible for water quality protection and management), and several other agencies, such as agriculture, forestry and transportation. For example, the State Forestry Administration normally has responsibility for forest and watershed management in headwater areas of watersheds, whereas the Ministry of Agriculture is responsible for farmland and livestock husbandry management in the middle and lower reaches of watersheds. Departments responsible for water transportation, energy development, fisheries and tourism may also have responsibilities for the planning and management of water and riparian resources. The diversity of responsibilities means that individual agencies will only take responsibility for those aspects in which they have an interest, and no single agency will assume responsibility for any watershed damage that may occur (He and Chen, 1998).

2.4.5 Lack of public participation

In China, public participation in planning and management is viewed as a voluntary activity and is relatively rare. In legal instruments, guidelines and principles for public input are sometimes provided, but these are generally not supported by any clear legislation (He and Chen, 2001; and Hu and Yu, 2005). For example, with the South-to-North Water Transfer Project described above, the public, including researchers, have been refused access to the planning process. Jiang (1999) conducted a public opinion poll that demonstrated that only 10% of respondents had even heard of this massive project. In addition to the lack of participation by the general public, potential opponents to any projects, who often include experts in the subject, tend to be excluded from any consultation (He *et al*., 2001). Current practice tends to favour a process by which an agency or company developing a proposal will only consider favourable comments, which are then presented to the decision-making authority; any objections are ignored, even if they are based on objective studies of the project. Wang *et al*. (2008) conducted a questionnaire survey of public participation in watershed planning in the Min River Watershed, with the results indicating that only 11% of respondents had heard of or participated in public activities related to the watershed. More than 87% of respondents are neither heard from nor participate in any public event (see Chapter 8).

Many of the current issues facing watershed management arise from planning procedures, the governance structure and the management tools that are currently in use (Wang, 1999; Yang *et al*., 2006). The main problems can be related to a lack of effective and integrated watershed planning, a lack of participation amongst stakeholders, the lack of management guidelines appropriate to the various scales of the watershed, and the absence of any planning for ecological restoration. Unlike the US and Canada, China as a centralised country, governance is adversely impacted by the lack of a basin-level management commission operating as an umbrella body that could delegates management roles and responsibilities to tributary and local-level bodies, the inefficiency of interagency cooperation, overlapping mandates amongst agencies, and the general malfunctioning of the governance systems (CCICED, 2005; Yang *et al*., 2006). Management could be more effective if provided with the appropriate tools, including practical policy guidelines, support for new technology, adequate long-term monitoring and surveillance, and mechanisms that would encourage public participation in planning and governance (CCICED, 2005; Yang *et al*., 2006).

2.5 ASSESSMENT OF CHINA'S WATER RESOURCES STRESS

An important element of this review is to assess the distribution of water stress across China as a key indicator for regional watershed management. The critical ranges and definition of stress indexes are still being actively discussed in the water resources community (e.g., Pfannkuch, 2003; Rijsberman, 2006). In China, the variation in topography, precipitation, natural resources, population, and economic development means that watershed management should be balanced with local socio-economic and cultural development as well as with environmental protection. There has been a considerable amount of research on this issue (e.g., Han and Ruan, 2002; Zhu *et al*., 2003; Jia *et al*., 2002; Zhu *et al*., 2003; Gu *et al*., 2007), mainly utilizing the same weightings or averages. Here, I have adopted indictors and standardized data from the China Sustainable Development Strategy Report 2007 developed by the Sustainable Development Strategic Research Group of the China Academy of Science. I used Hierarchical Cluster Analysis to classify 31 province/cities in China. The criteria and data collection are described below.

2.5.1 Water stress assessment indictors

The most widely used indicator of water stress is the Falkenmark indicator (Falkenmark *et al*., 1989). Falkenmark *et al*. (1989) suggested 1700 m^3 of renewable water resources per capita per year as a threshold, based on water requirements in the household, agricultural, industrial and energy sectors, and the needs of the environment. If water supply falls below 1000 m^3, a country will experience water scarcity, and below 500 m^3, absolute scarcity. The approach is easy to apply and understand, but does help to explain the true of water scarcity, and the multiple indicators are not widely applied due to the lack of data availability and definitions that are not intuitive (Rijsberman, 2006). It is beyond the scope of this review to evaluate the water stress criteria and indicators used by, amongst others, Shikomanov (1991), Raskin *et al*. (1997), Alcomo *et al*. (2000), Vorosmarth *et al*. (2000) and Rijsberman (2006). Gleick (2002) provides a thorough overview of the history, background, and limitations of water indicators and indices as measures of water well-being. Here, I use the data and criteria agreed by scientists from the Sustainable Development Research Group of China Academy of Science. The criteria and data are derived from the China Sustainable Development Strategy Report (2007). According to this report, water stress in China can be measured by three criteria: water resource stress, water environmental stress and water ecological stress. These three are further represented by eight indicators. Figure 2–1 shows the framework of water stress assessment, and Table 2–1 presents some of the data from the reports.

Water resource stress is a criterion that reflects the capacity of a region to supply water for targeted activities. There are three key indicators. The first is water scarcity, which is derived from water resource per capita and water distribution (density). The key threshold is 1700 m^3 of renewable water resources per capita per year. The second indicator is water demand, the consumption by human activities. The demand is represented by a number of ratios: renewal of water resources and arable land, renewal of water resources and mining, renewal of water resources and population, and renewal of water resources and GDP. The third indicator is water utilization, a combination of the degree of water exploration, and the ratio of water use structure and water use sufficiency. The critical ratio is water withdrawal for human use to total renewable water resources; and a threshold value of 40% has been set (Rijsberman, 2006).

Water environmental stress is a criterion dealing with water pollution from human activities, such as industrial and urban untreated waste water, and agricultural pollution. The two indicators are water point source pollution (determined by the amount of untreated urban and industrial waste discharge) and water non-point source pollution, calculated indirectly from the use of fertilizers, herbicides and pesticides.

Water ecological stress is a criterion related to the local ecological problems created by the inappropriate use of water resources. The three indicators are land degradation, derived from soil degradation and soil erosion, water-related disasters, determined by the incidence of floods and drought, and water ecological health, determined by the water demand for maintaining ecosystems such as wetlands.

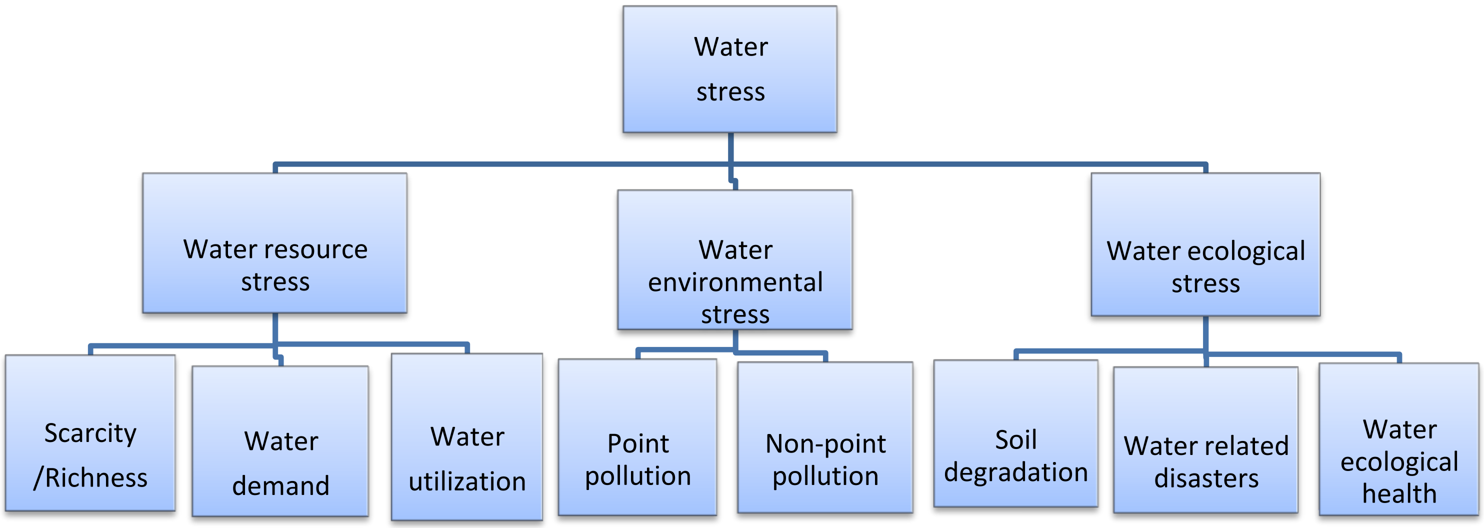

Figure 2-1. The framework of water stress assessment in China (Adapted from the China Sustainable Development Strategy Report, 2007).

Table 2-1. Standardized water stress indicators in different regions*. (Adapted from the China Sustainable Development Strategy Report, 2007).

		Water resource stress			Water environmental stress		Water ecological stress		
	Number	Scarcity/ Richness	Demand	Utilization	Point pollution	Non-point pollution	Soil degradation	Water related disasters	Water ecological health
Beijing	1	0.535	0.167	0.423	0.843	0.565	0.183	0.406	0.568
Tianjing	2	0.71	0.109	0.58	0.814	0.28	0.029	0.572	0.553
Hebei	3	0.775	0.555	0.823	0.355	0.295	0.331	0.477	0.578
Shanxi	4	0.835	0.296	0.56	0.21	0.04	0.418	0.853	0.421
Inner Mongolia	5	0.605	0.173	0.68	0.009	0	0.848	1	0.367
Liaoning	6	0.365	0.245	0.507	0.031	0.165	0.244	0.97	0.08
Jilin	7	0.16	0.095	0.483	0.002	0.08	0.126	0.883	0
Heilongjiang	8	0.18	0.273	0.597	0.004	0.025	0.148	0.63	0.231
Shanghai	9	0.495	0.299	0.58	0.566	0.525	0	0.084	0.167
Jiangsu	10	0.41	0.505	0.683	0.067	0.585	0.028	0.318	0.167
Zhejiang	11	0.16	0.113	0.353	0.001	0.58	0.127	0.213	000
Anhui	12	0.315	0.381	0.453	0.003	0.365	0.095	0.535	000
Fujian	13	0	0	0.387	0	1	0.086	0.29	0.01
Jiangxi	14	0	0	0.477	0	0.44	0.148	0.396	0.072
Shandong	15	0.044	0.68	0.59	0.051	0.525	0.161	0.455	0.022
Henan	16	0.415	0.505	0.467	0.025	0.44	0.127	0.381	0.126
Hubei	17	0.235	0.073	0.457	0.004	0.575	0.23	0.662	0
Hunan	18	0.06	0	0.473	0.001	0.585	0.134	0.456	0
Guangdong	19	0.19	0.208	0.39	0.001	0.715	0.044	0.228	0
Guangxi	20	0	0.132	0.55	0	0.3	0.031	0.383	0
Hainan	21	0	0	0.577	0	0.505	0.011	0.39	0

Table 2-1. Standardized water stress indicators in different regions. (Adapted from the China Sustainable Development Strategy Report, 2007). (Cont.)

		Water resource stress			Water environmental stress		Water ecological stress		
	Number	Scarcity/ Richness	Demand	Utilization	Point pollution	Non-point pollution	Soil degradation	Water related disasters	Water ecological health
Chongqing	22	0.205	0.018	0.3	0.001	0.17	0.444	0.552	0
Sichuan	23	0	0	0.393	0	0.195	0.227	0.375	0
Guizhou	24	0.13	0.028	0.38	0	0	0.295	0.351	0
Yunnan	25	0	0	0.517	0	0.035	0.254	0.347	0.333
Tibet	26	0	0	0.653	0	0	0.336	0.132	0
Shaanxi	27	0.29	0.244	0.46	0.001	0.095	0.552	0.741	0.11
Gansu	28	0.68	0.153	0.683	0.008	0.02	0.733	0.799	0.215
Qinghai	29	0.105	0.25	0.49	0	0.015	0.382	0.967	0.079
Ningxia	30	0.995	0.089	0.997	0.474	0.02	0.941	0.641	0.5
Xinjiang	31	0.34	0.042	0.82	0	0.03	0.941	0.316	0.255

(* data have been standardized for further analysis. Here 1 is high stress, while 0 is low)

2.5.2 Hierarchical Cluster Analysis:

SPSS 15 was used to conduct hierarchical cluster analysis for the data set to classify water stress in China. The analysis tested 3 to 6 groups and used the between-groups linkage method and squared Euclidean distance. The results (Figure 2–2) indicate that the provinces in China can be classified into three distinct groups in relation to water stress.

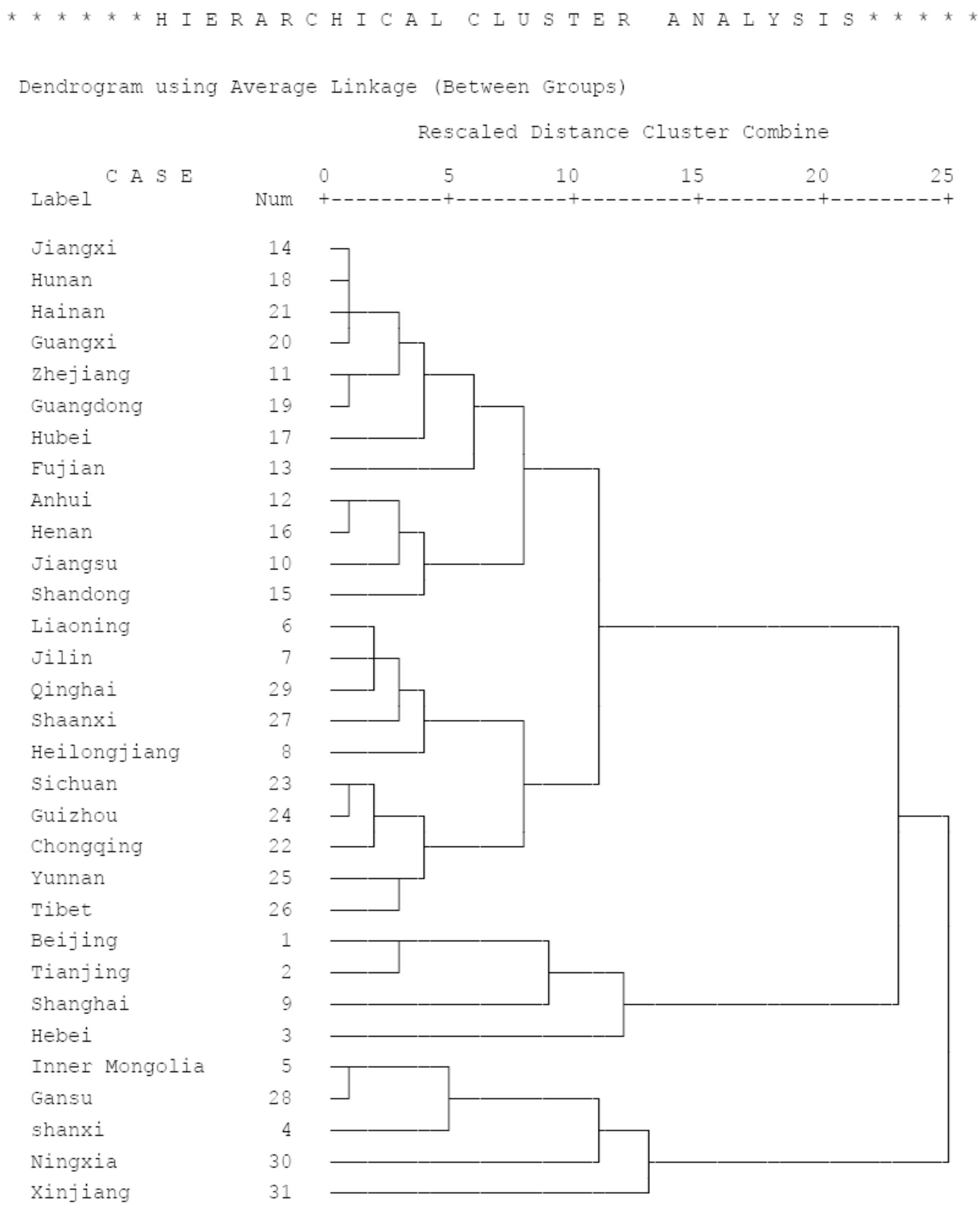

Figure 2-2. The result of cluster analysis of water stress assessment in China

The first group consists of Ningxia, Xinjiang, Gansu, Shanxi and Inner Mongolia, where four most important factors- water scarcity and utilization from water resources stress, and soil degradation and water related disaster from water ecological stress. Water stress is the result of a lack of precipitation, and where there are significant problems associated with land degradation, drought and aquatic ecosystems (Table 2-3). The area accounts for over one-third (36%) of China's total territory. The second group comprises Beijing, Tianjing, Hebei and Shanghai, where the most important issue is population-induced stress, resulting in high volumes of water utilization, water pollution from untreated industrial waste, urban sewage, and ecological problems as well agricultural-related pollution. The third group consists of the rest of China, where the ratio of water resource, population, land mass and economic development structure lies between the first and second groups. The water resources are relatively abundant, and the key factors from these areas are water related disaster and water utilization. Comparing to the original report used relatively simple calculations based on the same weight for each indicator and averaged all of the indicators together, then ranked by province. The results were grouped using the traditional distribution of Chinese industry (e.g., East, West, Centre and Northeast Industrial areas) and economic regions (Northeast, Northwest, Southwest, China North, China East and Central South), respectively, to compare water stress among the regions.

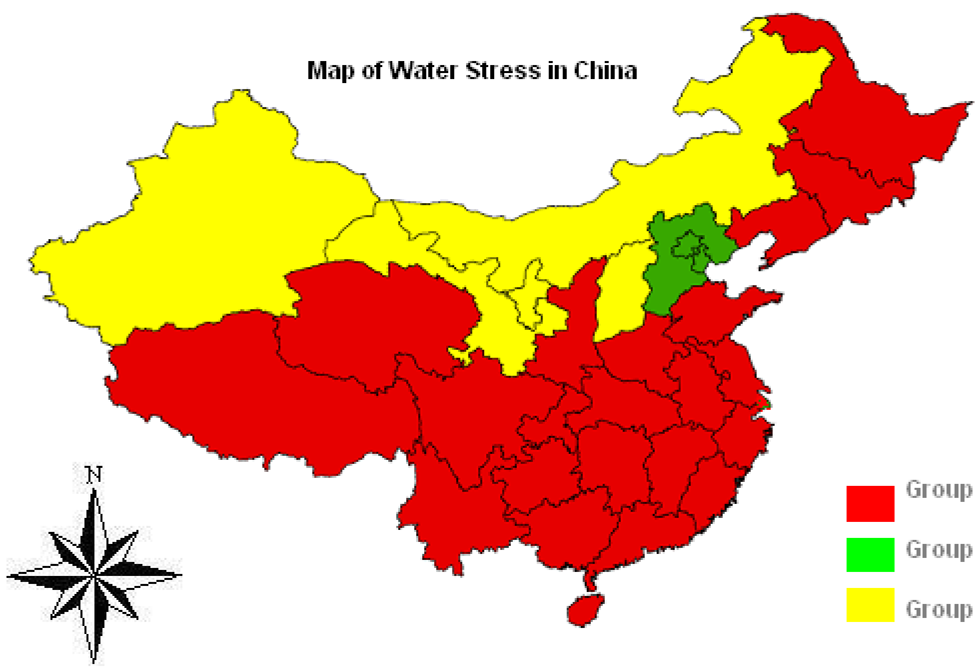

Figure 2-3. Map of water stress in China (Taiwan and the islands of the Southern China Sea are excluded due to lack of data).

The limitation of this analysis is that it only provides a general picture of regional water stress, and cannot be readily downscaled to smaller regions, such as cities, counties or watersheds. Watersheds are a more appropriate scale to understand water production/consumption. However, water is quite different from a static resource such as land, as it occurs in a very dynamic cycle of rain, runoff and evaporation, with enormous temporal and spatial variation (Rijsberman, 2006). The development of water-related infrastructure, including dams, canals, irrigation systems and waste treatment plants, as well as the characteristics of water utilization, make any assessment very difficult.

Table 2-2. Cluster grouping for water stress in Mainland China.

Group	Water resource stress			Water environmental stress		Water ecological stress			Average
	Scarcity	Demand	Utilization	Point pollution	Non-point pollution	Soil degradation	Water related disasters	Water ecologic health	
Group 1	0.691	0.151	0.748	0.140	0.022	0.776	0.722	0.352	0.450
Group 2	0.629	0.283	0.602	0.645	0.416	0.136	0.385	0.467	0.445
Group 3	0.148	0.170	0.484	0.009	0.336	0.192	0.484	0.056	0.235

Group	Region
Group 1	Ningxia, Xinjiang, Gansu, Shanxi, Inner Mongolia
Group 2	Beijing, Tianjing, Hebei and Shanghai
Group 3	Liaoning, Jilin, Qinghai, Shaanxi, Heilongjiang, Sichuan, Guizhou, Chongqing, Yunnan, Tibet, Jiangsu, Zhejiang, Anhui, Fujian

2.6 THREE CASES OF INTEGRATED WATERSHED MANAGEMENT IN CHINA

Appropriate watershed management is required if problems such as soil erosion, land degradation, declining water quality, depletion of wetlands and accelerated loss of biodiversity are to be addressed. The need is particularly great in China due to problems such as loss of water supply, severe flooding, and the spread of water-borne disease, shortages of food from crops that are dependent on irrigation (e.g., rice), land degradation, land-use change and soil and water contamination. By adopting a watershed management approach, the complex nature of cause-effect systems that determine such problems will be better understood (e.g., Yang *et al*.; 2006, CCICED, 2005). In addition to considering biophysical cause-effect relationships, integrated watershed management, involving the integration of social, economic and environmental factors, needs to be practised. This will require comprehensive interagency coordination, the cooperation of different levels of government, partnerships between the public and private sectors and the identification of an appropriate balance between development and protection (e.g., Calder, 1999; Yang *et al*., 2006).

In China, priorities for watershed management are the reduction of flooding and drought, the generation of power, changes in land management practices, reductions in the pressures on floodplains, and an increase in food supply (Yang *et al*., 2006; CAS Sustainable Development Strategic Research Group, 2007). This will require a dynamic process of cooperation, coordination and compromise, with a combination of appropriate administration, marketing mechanisms, enforcement of legal obligations, and public consultation and participation. There are a number of examples of the introduction of an integrated approach to watershed management in China. Some of these are described below.

2.6.1 The Mountain–River–Lake (MRL) program of Jiangxi province

The Mountain–River–Lake program, developed and implemented by the Jiangxi provincial government, appears to be unique in China, and is an example of successful watershed management. Its research approach, level of planning and intensive implementation led to the program being selected as a key Chinese project presented at the technical fair associated with the 1992 UN Conference on Environment and Development in Rio de Janeiro, Brazil. It was also featured at the Hannover World Expo in 2000 and at the Sustainable Development Summit in Johannesburg, South Africa, in 2002. The MRL program promotes the sustainable development of the region through environmentally sound policies, integrated regional management and the protection of the water resources (all of which were issues featured in Agenda 21).

Setting and issues

Jiangxi province is situated on the south bank of the mid-lower reaches of the Yangtze River, with almost all (97.2%) of the land surface draining into Poyang Lake. At 162,250 km^2, it is the largest freshwater lake in China. It collects water from the Gan, Fu, Xin, Rao and Xiu Rivers and releases the water into the Yangtze River. In the past, a rapid increase in the population of the area resulted in the conversion of forest in the catchment to grain production, land reclamation from the lake, pollution and over-fishing. In the early 1980s, the area impacted by water and soil erosion in the upper reaches of the Gan River reached 17,732 km^2, accounting for more than 54% of the area (Gong *et al*., 2006). Forest cover was reduced to 31.5%. The surface area of Poyang Lake was significantly reduced, its ecological functions were compromised, and floods occurred regularly. Sedimentation in the lower reaches was excessive, and the length of navigable channels was reduced from 12,000 km to 5,000 km. Adverse ecosystem effects were seen, including loss of biodiversity and the spread of disease (specifically, shistosomiasis). The degradation of the ecosystem was accompanied by increasing poverty, which proved extremely difficult to eradicate because of the connections between the environmental state of the watershed and its economy (Hu, 2005).

The dominant problems in the watershed (MRL, 2006) can be summarized as:

- Upper Reaches: serious water and soil erosion and loss of forest cover
- Middle Reaches: serious water pollution and siltation
- Lower Reaches (and the lake): reduction in the area of the lake, loss of biodiversity, increased frequency of flooding, development of a shistosomiasis epidemic
- The whole MRL Region: ecological imbalance and environmental deterioration, economic impoverishment and reduction in living standards

Development of a remediation program

The MRL program was based on a detailed examination of the watershed designed to assess its current status, involving more than 600 scientists. This enabled the principal problems to be identified, and established the cause-effect links for those problems.

A management strategy was developed that emphasized the inter-dependencies within the watershed: "to manage the lake the river must be harnessed, to harness the river the mountain must be managed, to manage the mountain poverty must be alleviated, and to alleviate poverty the human resource capacity must be strengthened" (MRL, 2006, p.12). It was realized by the program managers that regional social and economic development would require comprehensive watershed management, environmental protection, and the rehabilitation and reconstruction of fragile ecosystems. In addition, a pilot study was needed to explore and foster industrial models of sustainable development based on reasonable levels of exploitation of natural resources.

A commission and office was established to coordinate cooperation between agencies and between organizations located along the upper and lower reaches of the watershed. The governor or vice governor of Jiangxi province acted as the Director General of the commission. The functions of the commission included (MRL, 2006):

- Identification of broad watershed issues, development of management plans, and the conduct of holistic research and pilot studies.
- Facilitation of the cooperation between the upper and lower reaches and between different agencies with an interest in the watershed.
- Organization of international and national cooperation and technical exchanges.

A comprehensive investigation of the resources and environment of the Poyang Lake watershed enabled the local government and legislative body in Jiangxi to develop and approve a detailed legislative base for the management of the watershed, including 29 local statutes and 28 administrative regulations since 1985. At the same time, a long-term education program has been undertaken throughout the province that appears to have raised awareness of the laws, strengthened their enforcement, and improved the overall protection of the environment and the development of natural resources.

Major programs in the Poyang Lake watershed

Several large-scale projects have been launched over the last 20 years. About US$ 1.2 billion has been invested in a watershed ecosystem restoration program, which includes the return of reclaimed farmland to the lake, the reinforcement of the main banks, the relocation of households to new towns, and the eradication of the seasonal flooding of economically important land. Critical fragile ecological areas have been restored, the area of wetland has been greatly expanded, and the surface area of the lake increased by about 1200 km^2 (Hu, 2005). This program has been so successful that Poyang Lake is now recognized as an internationally important wetland by the Ramsar Convention and several other international agreements.

A program has been created that will ensure the better collaboration of different sectors, including plantation forestry, fisheries and agriculture through environment-friendly production techniques. Organic foods and products are being promoted, and attempts are being made to reduce soil and water erosion and untreated rural sewage. Several more sustainable farming models have been widely adopted, including the combinations of “vegetable–duck/chicken–fish”, “vegetable–pig–biogas–fruit” and “vegetable–pig–fish–fruit”. Rural households are combining latrines, barns and biogas ponds: faeces are fermented in the biogas pond, where the organic matter is decomposed and harmful bacteria are killed. The gas that is produced is used to provide energy for cooking and lighting. The biomass liquor is used as a fertilizer (MRL, 2006).

A comprehensive program has been developed to control shistosomiasis, a disease that has been present in the Poyang Lake area for many years (Hu, 2005). The program aims to prevent people from contacting contaminated water from the main water body by converting low-lying land into fish ponds, planting trees around the lake shore to establish a physical barrier, converting highland paddy fields into dry agriculture, preventing herds of grazing animals from accessing the lakeshore during the epidemic season, and popularizing public health education at grassroots levels. Poverty alleviation has been incorporated into the program to make it more attractive to local people.

Another program has aimed at strengthening local production through provision of more efficient processes. Based on industrial cluster theory (Porter, 1998) and its successful application along the east coast of China, the program has focused on the development of local economic activity through the integration of raw material production, products processing, logistics and marketing. The model is based on the concept that households manage agricultural raw materials, but have them processed at centralized locations. The centralized company is responsible for processing the products (in some cases it is local household associations and a company that jointly develop the manufacturing facility). The company or market centre is responsible for promoting the products. In these models, multiple mutual beneficial and risk-taking agreements have been signed to ensure the rights, benefits and responsibilities of all parties. Today, this model is widely adopted for activities as diverse as navel orange production in southeast Jiangxi, tea production in eastern Jiangxi, vegetable oil production in Yichun, Jiangxi, and aquaculture in eastern Jiangxi (Liu, 2005).

2.6.2 Min River Watershed management, Fujian

Setting

The Min River is located in south-eastern China, between 116°30' and 119°30' E and 25°20' and 28°25' N. It is the biggest river in Fujian Province and is among the ten biggest rivers in China (Figure 1–1). The headwaters of the Min River are situated at an elevation of about 2115 m in the Wuyi Mountains in the northwestern section of Fujian. Flowing generally east through the cities of Sanming, Nanping, and Fuzhou, the catchment covers an area of 60,992 km^2 and the river travels 2,872 km to reach the sea. The main river has a length of 559 km.

The Min River has played and continues to play an important role in the social, environmental and economic development of Fujian Province. Almost one-third of Fujian's population of approximately 11 million people live in the watershed. It accounts for over half of the total agricultural production, two-thirds of the commercial logging, and 60% of the drinking water in the province. GDP is around US$ 21.3 billion, 38% of provincial GDP and the watershed accounts for 57% of the industrial production of Fujian Province (Fujian Provincial Bureau of Statistics, 2005).

The watershed is used for generating hydroelectricity for urban and industrial use, irrigation, flood control, navigation, recreation, fishing and wildlife conservation. There are 29 large-scale hydropower stations in the watershed. A major construction project began in 1985, at ShuiKou (Figure 1–2), in Minqing County, to develop a power generation capacity of 1.4 million kilowatts annually. It is the biggest hydro-electric power plant in East China. The project was completed in 1996 and involved the resettlement of 67,000 people displaced by the floodwaters (Fujiann Chorography Compilation Committee, 2002). In addition to generating power, the dam is expected to help control flooding in the Min River Watershed.

Major problems

The Min River Watershed has a flabellate structure. The upper reach of the river is located within two main mountain groups: the Wuyi and Jiufeng–Daiyun Mountains. These mountains lie parallel to the coastline. The undulating topography and flabelliform layout of the terrain determine its vulnerability. The three main tributaries, the Jiangxi, Futunxi and Shaxi, join at the confluence in Nanping. The three tributaries drain 70% of the watershed, and 75–85% of the total discharge is present at the confluence. Downstream, the river flows through a narrow, steep, middle reach. Most rainfall occurs during the Monsoon season; the "plum rains" occur from March to June, accounting for 50–60% of precipitation, and the typhoon rains occur from July to September, accounting for 20–40% of precipitation. Warm, humid air blows from the Pacific Ocean across the mountains, and the topography results in large amounts of orographic rainfall.

Forest degradation linked to increase flooding. In recent years, over-cutting of the forest in the watershed has led to soil erosion, stream sedimentation, flooding and increased run-off (e.g., Chen, 1994; Zhao, 1997; Pan, 2003; Xie, 2004). Large clear-cuts and burning have caused erosion and reduced land productivity (Zhang, 1997; Lu and Gao, 2001; Tian, 2005). The natural forest cover (which consists of evergreen broadleaf forest) has declined by 43.5% over the last 27 years. The change in land-use pattern, especially a shift from natural vegetation to plantations and orchards has also decreased water retention and compromised soil conservation. For example, while the water-holding capacity of natural forest land is about 130 mm m^{-2}, that of tea plantations (classified in China as orchards) is approximately 27 mm m^{-2} (Wang, 1996).

There has been a significant change in the pattern of floods in the watershed over the last twenty years. Historical records indicate that there were 235 floods in the watershed between 982 AD and 1948. Since 1948, there have been 20 serious floods, with the flooding becoming more intense and severe since 1990. The statistics indicate that the return period of serious flooding (defined as a flow event of 20,000 m^3 s^{-1} at Zhuqi Hydrological Station) has decreased from once every four years over the last 100 years to every two years over the last 50 years, and has reached up to once or twice a year in the last 10 years. The most serious flooding in the history of the watershed (since 1609) occurred in 1998, with 175 fatalities and seven million people adversely affected, costing the province US$ 1.2 billion, including both direct and indirect damage (Zhang *et al*., 2000).

Inappropriate land management practices are exacerbating the magnitude of the damage. Traditional forest management practices in the watershed include clear-cutting, site preparation and cultivation that involves exposing the subsoil ("turnover cultivation" or tilling)[2], litter raking, large-scale monoculture plantations, and logging without leaving buffer zones in the riparian areas. Traditional agricultural practices include planting crops on steep slopes, tilling approaches to weed control in orchards (tea and fruit) and widespread use of herbicides, pesticides, and fertilizers to increase productivity. In recent years, fish farming in rice fields and reservoirs has become one of the main sources of water contamination. The poor management and over-exploitation of agricultural and forest plantation land has not only led to the degradation of ecosystems, soil erosion and stream sedimentation, but also lowered the soil productivity of the watershed and increased water contamination (Tang, 2003). Forest land represents 67% of the total area of eroding land, with orchards making up 25.8%, and crops 5.5% (Chen, 2000). Soil erosion has lowered land productivity, resulting in the increased use of chemical fertilizers in agricultural and plantation areas, adding to the pollution load and decreasing the soil infiltration capacity.

Industry pollution There are now 1,135 industrial mills along the Min River. Annually, 34.5 million tonnes of industrial wastes drain into the river. 85 mills generate over 0.5 million tonnes of waste water per year; 17 of these are pulp and paper manufacturers, 23 are chemical works, and seven comprise metallurgical industries (Chen, 2000). The main contaminants in the water are petroleum-derived wastes and amino-nitrogen; these have been exceeding class III of the national standard (Surface Water Quality National Standard, GB3838–88) by about 50% and 51%, respectively. In recent years, the rapid development of the animal husbandry industry has caused serious pollution in some segments of the watershed, with the industry contributing 62.5% of the total COD discharge and 63% of ammonia and nitrogen discharge. The waste discharge from residential areas in 2002 was 277 million tonnes, whereas that from industry was 280 million tonnes. Fertilizer use in the watershed was equivalent to 165,000 tonnes of nitrogen and 57,000 tonnes of phosphorous. The use of pesticide and herbicide amounted to 21,000 tonnes in 2003. In 2006, there were 12 accidents related to water pollution, and 23,741 environment-related conflicts. Official estimates (Fujian Environmental Protection Agency, 2005) indicate that by 2010 and 2017, the watershed GDP will be increased by a factor of 1.6 and 2.8, respectively (on the 2004 value), and urbanization will reach 54% and 63%,

[2] There is no English term for the soil cultivation practice used in China that involves turning over the soil regularly to remove all weeds. The nearest equivalent is tilling (Bruce Larson, University of British Columbia, pers. com., May 2008).

respectively. By 2004, watershed total COD and ammonia and nitrogen had reached 38.2% and 86%, respectively, of the capacity of the watershed environment.

Impacts on local communities Many cities, including Jiangou, Jiangyang, Sanming, and Shaxia, are located at the confluence of the three tributaries. About five million people inhabiting the basin are at risk from natural disasters and pollution. The Shuiko dam has reduced discharge and raised water levels upstream. Control of discharge from the reservoir is vitally important for the people both above and below the dam. Due to the huge increase in population and expansion of cities and farming areas along the lower reaches of the river, Fuzhou municipality, with three million people, faces extreme water shortages every late summer and early autumn. Since 1996, the water level has remained 0.5 meters below the top of the diversion tunnel for more than six months each year (Fujian Chorography Compilation Committee, 2002).

Lack of public participatory and interagency communication Although the watershed falls within the Fujian provincial territories, the river also crosses the boundaries of 36 counties and cities. The experience of recent watershed management suggests that a successful watershed management program largely depends on coordination among the counties and cities. The coordination of information sharing, planning, implementation and monitoring is paramount, especially the coordination between upstream and downstream administrations. Currently there are more than ten government agencies involved in the watershed administration, risking miscommunication and duplication of effort. Upstream forest management, agricultural practices, industrial sites, and pollution treatments are having a major impact on downstream sedimentation and water pollution.

Participation by farmers in the planning process and public involvement in management are both rare in China, but remain keys to the success of integrated watershed management. Until now, a "top-down" approach has been adopted, with central and provincial governments ignoring local stakeholders. The absence of any participatory decision-making amongst local communities and farmers, together with a lack of public education, have been claimed to be the main factors causing the failure of the programs (Wang, 1999; Jones *et al*., 2002).

Program for improvement

The health of the Min River Watershed is important to Fujian's social, cultural, environmental and economic development. In 2005, the Fujian Provincial government promulgated the Resolution on Comprehensive Measurements on Harnessing the Min River Environmental Issues (Fujian MZB (2005) 93) and the Min River Watershed Protection Plans (2006 – 2020) (Fujian Environmental Protection Agency, 2005). Between 2006 and 2010, the Fujian government is investing US$ 829.8 million in combating soil erosion, water contamination and flooding. There are several major elements to this investment program, described below.

One aspect will focus on developing comprehensive approaches to deal with water pollution from animal husbandry and aquaculture in the watershed by developing a zoning system, detailed monitoring and procedures for the recycling of waste. Local householders will be encouraged to develop innovative toilet, kitchen, and sewage outlet systems by adapting the "pig–biogas–grass–pig" cycle, or the "pig–biogas–fruit/tree/fungi/fish" cycle. Self-contained waste recycling systems will be encouraged. There will also be a focus on helping to develop municipal waste processing systems within the current economic models, such as BOT (build–

operate–transfer), wherein a private entity receives a franchise from the public sector to finance, design, construct, and operate a facility for a specified period, after which ownership is transferred back to the public sector. During the time that the company operates the facility, it is allowed to charge users appropriate tolls, fees, rentals, and charges (as detailed in an initial contract) to enable the project proponent to recover the initial investment, together with covering the operating and maintenance expenses of the project.

A second component is related to headwater protection and ecological restoration programs. Amongst other things, this part of the program is identifying headwater areas in need of protection. The restoration projects involve five steps, including the establishment of monitoring systems, the replacement of old machinery and technology, the promotion of ISO 14000 environmental management systems certification, the removal of dams, hydroelectric power stations and mining sites from ecologically sensitive areas and the rehabilitation of natural forests and ecological forests.

A third component consists of a recycling pilot study and demonstration program. This component is promoting energy and resource conservation, the more efficient use of resources and the development of recycling. The pilot study includes industrial, agricultural and regional recycling. The demonstration projects are based on the concept of "integration, circulation, coordination, and regeneration", and have developed different ecological agriculture models, such as an agroforestry model, a biogas model and a household-contained circulation model.

The final component relates to support for watershed management. It establishes the head of the local government as the individual legally responsible for regional environmental issues, environmental emergency response and pollution control. Under the umbrella provided by the local government chief's responsibility, an interagency cooperation coordination committee has been developed involving various levels of government. The committee consists of department heads from watershed-related sectors, such as forestry, agriculture, land resources management, environment protection, water resources management, health, finance, and planning. This committee is tasked with developing comprehensive watershed management plans and identifying the necessary financing sources, with identifying the responsibilities of each agency, with clarifying the mechanisms for interagency cooperation, and with encouraging public participatory mechanisms.

2.6.3 The Tai Lake experience

Setting

Tai Lake, with a surface area of 2,428 km^2, is the third largest freshwater lake in China. It is located in a sub-watershed of the Yangtze River in the centre of the Yangtze River Delta. Tai Lake serves multiple functions amongst which are floodwater storage, irrigation, navigation, water supply, waste disposal, aquaculture and tourism. It is the main source of drinking water for areas such as Wuxi and Suzhou. The lake is the site of China's most rapid urbanization and one of the largest influxes of rural migrant labour in the country. It currently serves more than 45.3 million people. The area is characterized by rapid economic development and the GNP of the Tai Lake watershed accounts for about 11.6% of China's GNP (MoWRM, 2008). In the period from 1980 to 2005, GDP increased from US$ 13.5 billion to US$ 303 billion, an annual increase of 11.6 % (Jin *et al*., 2006). As industrial enterprises gradually replace farming as the most important source of employment in the delta, the uncontrolled disposal of untreated wastes has increased along regional waterways, all of which lead into the lake. The local governments have allocated substantial budgets to combat pollution and reduce the rate of eutrophication. However, Chang (2002) has argued that these efforts have failed to address the primary cause of the problem: watershed damage arising from untreated household and industrial wastes, uncontrolled construction, aggressive conversion of wetland and riparian zones, and uncoordinated dam and weir management.

The main problems

A number of problems can be identified in the Tai Lake catchment. There is a major issue surrounding the demand for water, which exceeds supply. The average annual rainfall in the watershed is about 1141 mm (varying from 680 to 1550 mm), and the total received water is about 414 x 108 m^3. Of this, about 162.3 x 10^8 m^3 is usable, with runoff accounting for 84%, and groundwater for 16% (Table 2–3) (Yang *et al*., 2004). The per capita consumption of water in the delta area is 450 m^3, less than one fifth of national average (Gao and Miao, 2002; Ye, 2006). Rising pollution and the uneven temporal and spatial distribution of rainfall is exacerbating the conflict over water resources.

Table 2-3. Distribution of water resources in the Tai Lake catchment (Adapted from Yang *et al*., 2004).

(Unit: 10^8 $m^{3)}$

	Precipitation	Runoff	Underground	Total
Upper reaches	204	71.6	5.8	77.4
Lower reaches	210	65.1	19.8	84.9
Total	414	137	25.6	162

As mentioned above, the extent and severity of water pollution is increasing (Ye, 2006). In the 1950s and 1960s, Tai Lake had low nutrient inputs. Since then, eutrophication has occurred and has been associated with deteriorating water quality, particularly at the northern end of the lake, where the Yangtze River brings in large amounts of untreated effluent. Eutrophication is particularly serious during the low water period, which is at its most extreme in March. As the lake has become more eutrophic, seasonal fluctuations in nutrient concentrations have also become greater (Chang, 2002). Yang *et al*. (2004) reported that the total discharge of waste water (from industry and households) during the year amounted to 50 x 10^8 m^3. COD, BOD5 (biochemical oxygen demand), TN (total N) and TP (total P) concentrations were three times higher during the low water period than during the high water period.

Flooding occurs frequently in the Tai Lake area. From the Wuyue (228 BC) to the Dongjing (410 AD) eras, historical records indicate that there were 38 floods over the 638 years, a frequency of one event every 17.4 years. During the 933 years that extended from the start of the North Song dynasty (978 AD) to the end of the Qing dynasty (1911), there were 288 floods, a frequency of one every 3.2 years. There have been 13 floods in the twentieth century (Gao and Miao, 2002). In last two decades the groundwater table has been dropping at a rate of 20–50 mm/year (Yang *et al*., 2004), with the cities of Shanghai, Suzhou, Wuxi, Changzhou and Jiaxin facing ever-increasing problems as a result.

Tai Lake was once home to many species of endemic fish. However, the construction of dams and weirs in the waterways to connect the lake and the increased use of wetlands and riparian zones since 1950 have resulted in many endemic fish species becoming endangered, including Chinese sturgeon (*Acipenser sinensis*), Reeves shad (*Hilsa reevesii*), Chinese paddlefish (*Psephurus gladius*) and Rough-skinned sculpin (*Trachidermus fasciatus*) (Sun, 2005). There have also been deleterious effects on water quality, fisheries resources, and aquatic life. Dams have reduced water exchange and increased the frequency of water re-use, directly contributing to increased eutrophication. Increased use of wetlands and riparian zones for rice and fish farming since the 1950s has significantly reduced the lake's size (Chang, 2002).

Resolution of the problems

According to a State Environmental Protection Administration of China Report (State Environmental Protection Agency, 2005), the Chinese government has considered the prevention of water pollution in Tai Lake as a top priority since 1990. In the 9th Five Year Plan period, the Central Government and local authorities invested about US$ 1.2 billion in water treatment, and the figure for the 10th Five Year Plan was US$ 1.6 billion (13.22 billion Yuan), accounting for 60.2% of the total investment of the Plan. In the 11th Five Year Plan (2006–2010), the government is removing contaminated sediment, protecting and improving drinking water resources, controlling non-point source pollution, and developing an integrated lake management plan. The State Council of China has approved the proposal of the Flood Protection Plans for Tai Lake Watershed to develop a holistic flooding control system and the reinforcement of the embankment systems around the lake (State Council of China, 2008).

In order to improve environmental facilities, the Tai Lake Administration Authority and local city governments have developed a set of policies aimed at promoting market mechanisms to encourage environmental development, such as promoting the involvement of local private companies in municipal waste management, sewage water treatment and the development of service facilities. Waste management in particular has become an extremely profitable industry in China (e.g., Yang *et al*., 2006; Zhang, 2006).

A water quality information exchange mechanism has been developed that should control water quality and enhance interagency cooperation. Information on water quality in border areas is released monthly. The People's Governments of Jiaxing and Suzhou have also set up mechanisms to both prevent pollution and provide early-warning of any pollution incidents (State Environmental Protection Agency, 2005).

A major event, called the "Tai Lak Zero Clock Action" was initiated by SEPA at midnight on January 1st, 1999. Local law enforcement agencies joined SEPA in examining the waste water, air and solids pollution around the lake. Overnight, infringements by 1035 manufacturing plants were detected; of these, 42 were forced to close (Xinhua, 1999). However, although there have been significant accomplishments, pollution in the lake basin still remains a major issue, with nitrogen remaining high, and eutrophication still occasionally evident in some areas.

The three case studies described here should not be viewed as unqualified successes. Each has failed at some point, so there is no room for complacency. Moreover, in large-scale watersheds such as those of the Yangtze, Yellow and Huai Rivers, the situation is deteriorating. Current government plans to solve the fundamental problems of water contamination, soil erosion and water conservation are ambitious. However, central and provincial watershed development agendas and long-term investment plans are dominated by the construction of dams, diverse water facilities, canals, and water treatment plants. Soft-path solutions (Gleick, 2003) and integrated watershed management are slowly developing from the grassroots level. The complexity of the social, economic and environmental expectations along with the existing culture of resource exploitation and the continued use of traditional management practices are severely complicating any attempts to resolve the problems.

2.7 INTEGRATED WATERSHED DEVELOPMENT STRATEGIES

China's severe water pollution, water shortages and watershed destruction have contributed to population movement, health risks, and food security problems and rising income disparities, and ultimately, are affecting China's economic, political and social stability (Turner, 2006 and Gleick, 2008). A core strategy for watershed management is to balance development and protection in such a way that it is consistent with local social, economic and environmental needs. A key factor determining the success of any program is whether all the stakeholders can be brought together in planning and implementing watershed development strategies. The experience from Poyang Lake, Tai Lake and the Min River Watershed (also see CCICED, 2005; Yang *et al*., 2006), from the International Rhine Commission (Smits, 2005), Tennessee Valley Authority (USA) (Tan and Wan, 2001; and Yang et al., 2006 and Heathcote, 2009), the Fraser Basin Council (Canada) (Blomquist et al., 2005) and from many others (USEPA, 1997 and Mody, 2004) suggest that most problems have stemmed from centralized management approaches that failed to take into account the emphasis placed by local stakeholders on rapid economic growth (e.g. Wang, 1999; Yang *et al*., 2006). Given current trends, it is likely that watershed management issues will continue to dominate the environmental debate in China (Smits, 2005; Turner, 2006; and Gleick, 2008). A number of future issues can be identified, summarized below.

Integrated watershed management represents an important approach to maintain and enhance watershed health. However, the evidence provided above indicates that the integration needs to be broad, and should include all aspects of watershed resources (natural resources, human resources, political resources and science and technology) and watershed issues (economic development, water shortages, natural disasters, biodiversity, soil erosion and sedimentation, resource depletion, poverty), as well as involving multiple agencies and jurisdictions and local communities (e.g. Smits, 2005; CCICED, 2005; and Yang et al., 2006). Smits (2005) and Yang et al. (2006) gave a thorough overview of the history, issues and development of the Rhine River and pointed out that China should motivate its own stakeholders and pull together watershed resources as much as possible in combating current watershed problems.

There is a need for improved governance in the form of improved legal systems and the establishment of institutions responsible for the coordination of watershed management. The experiences from inside and outside of China, as I illustrated above, have shown that the development of integrated watershed management legislation, regulations and comprehensive management plans is an enormous step in securing the sustainability of watershed management. Such institutional arrangements secure the legal position of the coordinating institution, the obligations of the stakeholders, and the mechanisms to resolve any conflicts (Calder, 1999; Smits, 2005; Yang et al., 2005).

An improvement in inter-governmental agency communication and in the communication between stakeholders throughout the entire watershed is necessary. As with the evidence provided from the MRL program, each stakeholder group needs clear responsibilities, with the government adopting a leadership role, individual departments fulfilling their statutory responsibilities, adequate supervision by the environmental agency, appropriate treatment of effluents by local enterprises, and surveillance and participation by the public. An assessment of the effectiveness of watershed management should form the basis for the evaluation of the performance of those in control. The Central Government of China is introducing Green GDP and auditing systems that will allow the public and Central Government to assess the development of regional economies in the light of resource use and environmental degradation. These systems should promote a move away from the focus on economic development that currently dominates in most provinces.

Effective implementation models are required (e.g. MRL, 2006, Lu et al., 2007). The principles of sustainable development (Muschett and Campbell, 1997) need to be used to guide watershed management. Appropriate plans need to be developed and implemented. A range of techniques should be employed. As indicated by the current water situation, governance approaches should include enhancing water use efficiency, environmental laws and regulation enforcement, the use of smart economics and market mechanisms, and improving public involvement (Gleick, 2008). An ecocentric approach (Smits, 2005) could be critically important. First, there is a need to try to understand the watershed ecosystem; then, via a bottom-up approach in which the local people are truly involved, alternative livelihoods that conflict as little as possible with nature should be identified. Market mechanisms could be combined with the financial leverage of government, so that watershed management could better balance the benefits of all stakeholders and thus gain their support (Smits, 2005, p35).

Interdisciplinary research is needed to solve the complex integration of population, resources, environment and development. Particularly in China, social science research is needed on the introduction of democratic decision-making within the current Chinese governance systems (e.g. Wang, 2003; Yang et al., 2006, Gleick, 2008). Research is also required on ways to enhance public environmental education, and to encourage public participation in watershed planning and monitoring (Yang et al., 2006).

2.8 CONCLUSION

Watershed management has occurred throughout the history of Chinese civilization and there have been many success stories. However, as a result of the economic development and population growth over the last thirty years, ecosystem degradation and water pollution have become key issues jeopardizing the social structure, environmental protection and living conditions in China. China's current watershed management mechanisms do not deal with watershed problems effectively. Future watershed management in China should include the improvement of its legal system and law enforcement; the construction of an appropriate management structure, complete with inter-agency working mechanisms; the development of a structure that could better balance the interests of all stakeholders; an integrated approach to watershed planning; greater stakeholder participation; better information exchange, and better and more comprehensive public education.

2.9 REFERENCES

Alcamo, J., Henrichs, T. and Rosch, T. 2000. World water in 2025: global modeling and scenario analysis. In: Rijsberman, F.R. (Ed.), *World Water Scenarios Analyses*. World Water Council, Marseille, France.

An, S., Li, H., Guan, B., Zhou, C., Wang, Z., Deng, Z., Zhi, Y., Liu, Y., Xu, C., Fang, S., Jiang, J. and Li, H. 2007. China's natural wetlands: Past problems, current status, and future challenges. *Ambio* 36(4), 335–342.

Anonymous 2007. Zhengbai Irrigation Canal. China Watershed Resources and Hydropower Net. http://www.slsdgc.com.cn/water/theme1/info.php?id=1892. Accessed Oct 14, 2007.

Biswas, A.K. 2004 From Mar del Plata to Kyoto: an analysis of global water policy dialogue, *Global Environmental Change* Part A, 14 (S1). Focus on the International Year of Freshwater, 81-88.

Cannon, K.A. 2006. Water as a source of conflict and instability in China. *Strategic Analysis* 30 (2), 310–328.

Calder, I.R. 1999.*The blue revolution: land use and integrated water resources management*. London, Earthscan Publications Ltd.

CAS Sustainable Development Strategic Research Group 2007. *China Sustainable Development Strategy Report 2007 – Water: Governance and Innovation*. Science Press: Beijing, 388pp.

CCICED 2005. Lessons Learned for Integrated River Basin Management. *Proceedings of International Symposium on Integrated River Basin Management*. CCICED Task Force Task on Integrated River Management. China Environmental Science Press: Beijing.

Chang, W. 2002. *Lake Tai: China's 3rd Largest Lake Fights to Survive*. A September 2002 Report from the U.S. Consulate in Shanghai. http://www.usembassy-china.org.cn/sandt/laketai.htm (Dec. 2006).

Chandra, S. 1990. *Hydrology in ancient India*. National Institute of Hydrology, Rookee, India, 106 pp.

Chen, C.M. 2000. The impact of the industrial structure and distribution on environment around Min river basin. *Journal of Fujian Geography* 15(1), 14–17.

Chen, S.J. 2007. *History of China water resource management*. China Water Resources Management Publishing House: Beijing, 134pp.

Chen, S.S. 1994. The causes of flooding and prevention in the Min River Watershed. *Fuijian Water and Soil Conservation* 3, 26–30.

China's Agenda 21. 2003. Whitepaper on China's population, environment and development in the 21st century. http://www.acca21.org.cn/english/index.html. Accessed on 15, Oct. 2007.

China's Water Management Modernization Research Group 2002. *China water management modernization report*. China Watershed Resources Publishing House: Beijing.

China's Water Management Modernization Research Group 2004. *Study on China's water management modernization*. China's Water Management Modernization Research Group. February 14, 2004. Accessed on Oct.15, 2007. http://www.hwcc.com.cn/newsdisplay/newsdisplay.asp?Id=93175

Economy, E.C. 2004. *The river runs black: the environmental challenge to China's future.* Cornell University Press: Ithaca & London, 337pp.

Feng, J.M., Wang, T., Qi, S.Z. and Xie, C.W. 2005. Land degradation in the source region of the Yellow River, northeast Qinghai–Xizang Plateau: classification and evaluation. *Environmental Geology* 47, 459–466.

Fujian Chorography compilation Committee 2002. *Fujian chorography*. Fuzhou, Fangzi

Publishing.
Fujian MZB 2005. *Resolution on comprehensive measurements on harnessing the Min River environmental issues*. Document # 93. Fujian Provincial Government, China.
Fujian Environmental Protection Agency 2005. *The Min River watershed protection plans*. Fujian EPA. Fuzhou, China.
Fujian Provincial Bureau of Statistics 2005. *Fujian statistical yearbook.* China Statistics Press: Beijing.
Gao, J.F. and Mao, X.W. 2002. Tai Lake regional economic development and water demand. *Science and Technology Report* 4, 62–64.
Gleick, P. 2003. Soft path's solution to 21st-century water needs. *Science* 320, 1524–1528.
Gleick, P. 2008. *The world water 2008-2009: the biennial report on freshwater resources.* Island Press: pp 432.
Gong, X.M., Li, K., Liu, Y.Q. and Fu, C.J. 2006. Soil erosion and development trends in the Gan River watershed. *Journal of Yangtze* 37(8), 48–51.
Grover, V.I. 2006. *Water: global common and global problems*. Enfield, NH: Science Publishers.
Gu, H. 2006. *Historical yearbook of China water management*. China Watershed Resources and Hydropower Publish House. Beijing.
He, D.W. and Chen, J.S. 1998. Water environment management in China: problems and perspectives. *Advances in Environmental Science* 6(5), 20–28.
He, D.W. and Chen, J.S. 2001. Issues, perspectives and need for integrated watershed management in China. *Environmental Conservation* 28(4), 368–377.
Hu, Z.P. 2005. *Study on the comprehensive management of Poyang Lake watershed. Lessons learned for integrated river basin management*. China Environmental Science Press: Beijing, pp. 15–25.
Hu, K.P and Yu, X.G. 2005. Bridge over troubled waters: the role of the news media in promoting public participation in river basin management and environmental protection in China (Chapter 8). IDE Spot Survey No.2. *Promoting Sustainable River Basin Governance — Crafting Japan-U.S. Water Partnerships in China. pp. 125-140.*
International Association for Water Law 1976. *Recommendations of the Caracas Conference on Water Law and Administration*. 8-14 February 1976, pp. 16-18.
Jiang, W.L. 1999. *On the value of water resources*. Academic Press: Beijing.
Jin, X.L., Gao, J.F. and Zhao, G.J. 2006. Impacts of 20 years social economic development in the trend of aquatic environment of the Tai Lake Basin. *Resources and Environment in the Yangtze Basin* 15(3), 298–302.
Jones, C.R., Palmer, M., Motkaluk, S. and Walters, M. 2002. *Watershed health monitoring: Emerging technologies*. Lewis Publishers: Boca Raton.
Kong, Z.H., Zhang, X.S. and Zhou, G.S. 2002. Agricultural sustainability in a sensitive environment – a case analysis of the Loess Plateau in China. *Journal of Environmental Sciences* 14, 357–366.
Li, Z.L., Ping, Y. and Bin, X. 2003. The study of land desertification in transitional zones between the MU US desert and the Loess Plateau using RS and GIS – a case study of the Yulin region. *Environmental Geology* 44, 530–534.
Li, Z.Y. 2003. A policy review on watershed protection and poverty alleviation by the Grain for Green Programme in China. Proceedings of the Workshop Forests for Poverty Reduction: Opportunities with Clean Development Mechanism, Environmental Services and Biodiversity on 27–29 August 2003, Seoul, Korea. http://www.fao.org/docrep/008/ae537e/ae537e00.HTM.

Lin, J. Y.1987. The household responsibility system reform in China: A peasant's institutional choice. American Journal of Agricultural Economics 69 (2):410-415
Liu, J.C. 2005. Accelerating Jiangxi industrialised agricultural development. Accessed Oct. 14, 2007. http://news.aweb.com.cn/2005/12/4/10155928.htm.
Lu, J.B., Wu, J.G., Fu, Z.H., Zhu, L. 2007. Water Hyacinth in China: a sustainability science-based management framework. Environmental Management. 40: 823-830.
Lu, W. and Gao, F. 2001. Impact of clear-cutting on soil physical and chemical property. *Forestry Engineering* 17(3), 17–18.
Ma, D.T., Cui, P., Zhang, J.S. and Li, H.L. 2005. Formation causes and features of mudflows in the Loess Plateau, China. *Arid Land Geography* 28, 435–440.
MoWR 2008. *Flood protection plan for Tai Lake watershed*. Ministry of Water Resources of China. http://www.mwr.gov.cn/ztpd/tszt/lyfhgh/thly/20080326090622d82ebc.aspx.
MRL 2006. *Integrated management of Poyang Lake Basin, Jiangxi, P.R. China*. Presented by The Mountain–River–Lake Program Office. Nov. 2006. Nanchang City, China.
Mody, J. 2004. *Achieve accountability through decentralization: lessons for integrated river basin management.* World Bank Policy Research Working Paper 3346, June 2004.
Muschett, F.D. and Campbell, C.L. 1997. *Principles of sustainable development*. CRC Press, Boca Raton. 176pp.
Pan, M.Z. 2003. Cause of flooding in Min River and biological protection. *East China Forest Management* 17(2), 35–39.
Pan, Y. 2006. *Economic development and environmental protection*. State Environmental Protection Administration of China. Available at: http://www.sepa.gov.cn/hjyw/200612/t20061220_97538.htm. Accessed on 12 March 2008.
Pfannkuch, H.O. 2003. Is the water stress index an adequate indicator of water scarcity for developing countries? Geological Society of America Bulletin 35 (6), 158.
Porter, M.E. 1998. Clusters and the new economics of competition. *Harvard Business Review* (November December 1998), 77–90.
Qiu, J. 2007. China’s green accounting system on shaky ground. *Nature* 448(2): 518-519.
Raskin, P., Gleick, P., Kirshen, P., Pontius, G. and Strzepek, K. 1997. *Water futures: Assessment of long-range patterns and prospects*. Stockholm Environment Institute, Stockholm, Sweden.
Rijsberman, R.F. 2006. Water scarcity: factor or fiction? *Agricultural Water Management* 80: 5–22.
Ren, M.E. and Zhu, X.M. 1994. Anthropogenic influences on changes in the sediment load of the Yellow River, China during the Holocene. *Holocene* 4, 314–320.
Salman, M. A. and Bradlow, D. D. 2006. *Regulatory frameworks for water resources management: a comparative study*. World Bank Publications: Washington. D.C. P.198
Shiklomanov, I.A. 1991. The world’s water resources. In: Proceedings of the International Symposium to Commemorate 25 Years of the IHP, UNESCO/IHP, Paris, France, pp. 93–126.
Smit, A.J.M. 2005. Evolution of river basin management in the Rhine River Basin and lessons for China in its quest to develop a sustainable land use and water management strategy. *Proceedings of International Symposium on Integrated River Basin Management*. CCICED Task Force Task on Integrated River Management. China Environmental Science Press: Beijing.
Smil, V. 1993. *China’s environmental crisis: An inquiry into the limits of national development*. M.E. Sharpe, Armonk. 257 pp.
State Council of China 1998. *National ecological environmental construction development plan*. The State Council of PRC. Guofa 1998(36). Nov. 7th, 1998.

State Council of China 2008. *Approval for flooding protection plans for the Tai Lake watershed*. The State Council of PRC. Guohan 2008 (12) Feb. 26. 2008.
State Environmental Protection Administration 2005. China water pollution prevention and control: Successful cases in China. Nairobi, Kenya. 21–25 February, 2005. http://www.unep.org/GC/GC23/documents/China-Water-Pollution.pdf.
State Environmental Protection Administration and the National Bureau of Statistics of China 2006. *China green national accounting study report 2004*. Available at: http://www.sepa.gov.cn/plan/gongwen/200609/P020060908545859361774.pdf. Accessed on 12 March 2008.
State Forestry Administration 2006. *2005 China forestry development report.* China Forestry Publishing House: Beijing, 151pp.
State Forestry Administration 2007. *China forestry statistical yearbook*. China Forestry Publishing House: Beijing.
Sun, L.L. 2005. Changjiang fish species reduced one-third. Endangered fish species survey. Environmental Protection Bureau of Jiangsu Province. http://news.eastday.com/eastday/node81741/node81763/node136279/userobject1ai2051974.html.
Tan, X.M. 2005. *The history of irrigation and flood control*. China Watershed Resources and Hydropower Publish House: Beijing.
Tan, G.L. and Wan, J. 2002. River Basin Management in Tennessee Valley, USA. *China Water Resources* 10: 157-159.
Tang, S. 2003. Soil erosion evolution and factors analysis ion Northern Fujian area. *Soil and Water Conservation of China* 8, 20–21.
Tian, D.L. 2005. *Chinese fir ecosystem functioning process*. China Science Press: Beijing.
Tuner, J. L. 2006. *New Ripples and Response to China's Water Woes*. Woodrow Wilson International Center for Scholars, China Brief, Volume 6. Issue 25, December, 19, 2006.
United Nations/World Assessment Programme 2003. *The United Nations water development report: Water for people, Water for life.* United Nations: New York.
Upadhyay, K.P. 2003. Reflection on two decades of watershed management experience in Asia (1983 to 2003). *Watershed Management: Water Resources For the Future*. International Conference Proceedings, Porto Cervo, Sassari, Sardinia, Italy, 22–24 October 2003. http://www.mountainpartnership.org/common/files/pdf/A0438E.pdf#page=53
US EPA. 1997. Top 10 Watershed Lessons Learned. http://www.epa.gov/owow/lessons/lessonspdfs/top10.pdf. Accessed on May 20, 2009.
Vorosmarty, C.J., Green, P., Salisbury, J. and Lammers, R.B. 2000. Global water resources: vulnerability from climate change and population growth. *Science* 289, 284–288.
Wang, G.Y. 1996. Study on the biomass and productivity in young mixed Chinese fir. *Journal of Fujian Forestry College* 16(2), 156–159.
Wang, G.Y., Innes, J.L., Zhang, X.P. and Wang, J.X. 2008. Public awareness and conception on Min River watershed management and development, Fujian, China. *Society and Natural Resources*, submitted.
Wang, G.Y., Innes, J.L., Lei, J.F., Dai, S.Y. and Wu, W.S. 2007. China's Forestry Reforms. *Science* 318: 1556–1557.
Wang, L.X. 1999. *Watershed management*. China Forestry Publishing House: Beijing.
Wang, L.X. 2003. *Soil and water protection*. China Forestry Publish House: Beijing.
Wei, S. 2005. Zhengguo: the first person introduce irrigation systems. Water Control: 27 http://www.cqvip.com/QK/96687X/200702/23779476.html.
Wei, X.H., Sun, G., Liu, S.R., Jiang, H., Zhou, G.Y. and Dai, L. 2008. The forest–streamflow

relationship in China. *Journal of the American Water Association* 44 (5), 1076–1085.
Xie, J.S., Yang,Y.S. and Chen, G..S. 2004. The study on cause of flooding in the upper reach of the Min Watershed. *Fujian Water and Soil Conservation* 11, 12–17.
Xinhua 1999. Tai Lake Zero Clock Action. Xinhua Daily News. Accessed on Oct 15, 2007 http://www.envir.gov.cn/info/np/file.asp?file=991-1-20.txt.
Yang, G.S. and Liu, L.Y. 1992. Land desertification along the Great Wall in the north of the Loess Plateau. *Chinese Journal of Arid Land Research* 5, 53–57.
Yang, G.S. and Yu, X.B. 2004. *Tai Lake Watershed Management: Introduction to Integrated River Basin Management*. pp. 206–219. Science Press: Beijing.
Yang, G.S., Yu, X.P., Li, H.P. and Gao, J.F. 2006. *Introduction to integrated watershed management.* Science Press: Beijing, 238pp.
Ye, J.C. 2006. *Improvement watershed management in Tai Lake Watershed. Watershed resource management: Innovation and practices*. China WaterPower Press: Beijing.
Zhang, D.H. 1997. The impact of clear-cutting on nutrient on movement. *Journal of Natural Resources* 12(4), 343–348.
Zhang, G.F., Chen, R.Y., Zen, J.R. and Lin, W.G. 2000. A study on floodwater and fragility of environment in Min Valley. *Journal of Soil and Water Conservation* 20(4), 51–55.
Zhang, S.M. 2006. Discussion on issues in implementing ICM approach in Tai Lake Basin. *Conference Proceedings of the Sino–Dutch Water Innovation Seminar*, Shanghai China. May, 18–19, 2006.
Zhao, S.P. 1997. Hazard assessment for mountain torrents on the upper reach area of the Min River. *Geographical Research* 16(1), 99–103.
Zheng, L.D. 2004. *History of watershed resource management.* China Water Resources Management Publishing House: Beijing, 305pp.
Zheng, L.D. 2006. JingHang Canal: the epic of the Mother Earth. *China National Geography.* Vol.5. http://tech.sina.com.cn/d/2006-04-30/0956925021.shtml. Accessed Oct 14, 2007.
Zhou, J.C. 2007. *Economic dialectic of a stricken nation*. Financial Times. http://211.81.31.53:88/index/showdoc.asp?blockcode=zjbi&filename=200701252378. Accessed, Oct 15, 2007.

3 MAJOR CHALLENGES FACING THE SUSTAINABILITY OF THE FOREST SECTOR IN CHINA[3]

3.1 INTRODUCTION

China's rapid economic growth has had significant impacts on its forestry sector and the global trade in wood. In just a few years, China has become the world's largest exporter of wood products (Hamilton, 2006; Wang *et al.*, 2007), and recently overtook Japan as the world's second largest importer of wood products (after the USA). China is also the world's largest importer of softwood and hardwood logs. Its rapid emergence in the furniture export business has enabled it to capture almost 50% of the US market, prompting a restructuring of the US furniture industry (Zhu, 2007), and low-priced Chinese wood exports have fuelled trade disputes with the USA and Europe. Environmentalists have been amongst the most critical of the unbridled economic growth: "China is already the biggest driver of rainforest destruction. Half of all rainforest logs head for China" (McCarthy, 2005); "If (China) consumes paper at the same rate we do, it will (in 2031) consume twice as much paper as the world is now producing. There go the world's forests...." (Brown, 2006). Despite publications such as that of Richardson (1990) and Zhou (2006), forestry in China remains a largely unknown entity because of the difficulty of accessing reliable information about the sector. In practice, there are major inconsistencies in the information that is being made available through both official and unofficial sources. For example, before 1998, forested land was defined as an area of forest with 30% or more canopy cover, but after 1998, any forest with 20% or more cover was considered as forest. Such changes are often missed in reports about forestry in China, resulting in the propagation of serious errors.

While the exact state of China's forestry sector is difficult to quantify, it is clear that China's forestry is currently experiencing the most rapid development in its history (Wang et al., 2007), and that China is experiencing a number of serious social, economic and environmental crises related to forestry. Annual floods exacerbated by uncontrolled logging and soil erosion have left millions homeless, huge sandstorms have created major problems for urban centres such as Beijing, the area of farmland affected by drought has tripled since 1950, and the quality of drinking water throughout the country remains a major concern (Yang, 2008). Pan Yue, Deputy Minister of the Environmental Protection Agency of China, has warned that "One-third of the urban population is exposed to heavily polluted air; 300 million rural residents drink unsafe water; and one-fifth of China's major cities fail to meet the country's minimum standards for drinking water" (Pan, 2006; Turner, 2006 and OECD, 2007).

The Chinese government is acutely aware that it must take measures to mitigate environmental damage if it is to sustain its economic growth and rural stability (Yang *et al.*, 2006). Estimates of the GDP lost due to environmental damage in 2006 range from 3% to 10% (Economy, 2007).

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[3] A version of this chapter 'Major challenges facing the sustainability of the forest sector in China' has been accepted for publication in *Forest Policy and Economics*. Authors: Wang, G.Y., Innes, J., Wu, W. S., Dai, S.Y. At the request of the external examiner, the version presented here differs significantly from the version that will be published.

China has introduced a series of forestry programs and new policies to expand its wood growing and manufacturing base, reduce incidents of natural disasters, improve degraded lands and provide more sustainable livelihoods for thousands of forestry-dependent communities (Wang *et al*., 2007). The programs reflect the growing recognition that forests can make to environmental protection and rural livelihoods, in addition to the more traditional focus on wood production (c.f. Liu, 2007a). The implementation of the programs is expected to lead to major transitions in the forestry industry, from felling mainly natural forests to the utilization of plantations; from deforestation for agriculture to the conversion of cultivated land to forestry and pasture, from the free exploitation of ecological services to payments for these services and from state control over forestry to involvement of the whole society in the sector (Zhou, 2006).

3.2 CHINA'S FORESTRY IN A NEW CRITICAL TRANSITION ERA

China's forestry has been changing drastically since the country was affected by devastating floods in 1998. The Central Government has launched a series of key national programmes and forest policy reforms. The scale and investment of these forestry programmes are already producing some tangible benefits to forest cover, the wood industry and rural livelihoods. Large areas are protected from logging, huge afforestation programmes are underway, and ongoing privatization offers hope of more efficient and effective operations that can create jobs and stimulate economic growth (Wang *et al*., 2007, 2008). China has achieved a measure of success in meeting some of environmental challenges, including increased afforestation, investment in forestry, expansion of the wood industry, reduction of harvesting to protect natural forests, growth in wood trade and increases in forest cover.

In the following analysis, I examine the major challenges facing the sustainability of the forest sector in China using statistical data derived from the annual China Forestry Statistical Yearbooks.

Reforestation and afforestation. There have been three peaks of reforestation in the last 56 years (Figure 3–1). The first stage (1956–1960) occurred during the Great Leap Forward, when there was large-scale harvesting to fuel the production of iron and steel (Judith, 2001). The second period of afforestation (1983–1985) took place after China's first (failed) attempt to privatize forestland. The third occurred in 2001–2004, with the implementation of the Six Key Forestry Programs (SKFPs). The first two periods coincided with heavy logging, and only the third period was accompanied by a reduction of logging and the adoption of more ecological practices. Between 2001 and 2007, 31.6 million ha. of land have been planted with trees (State Forestry Administration, 2008).

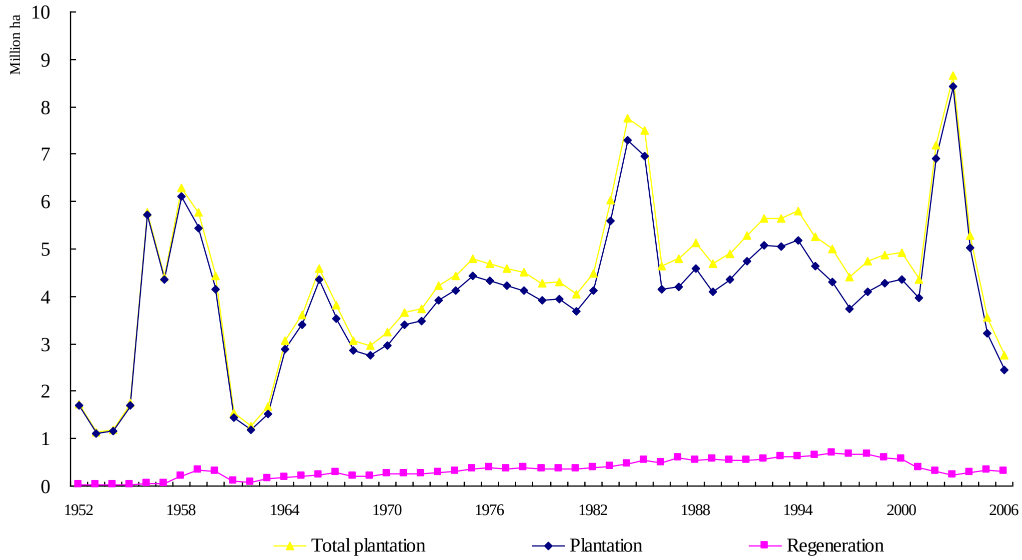

Figure 3-1. Afforestation and regeneration since 1949. (Source: Adapted from data presented in the annual State Forestry Administration reports 1993–2006).

Investment in forestry: Investment in the forest industry has remained constant if inflation is factored into the values. However, investment in silviculture and afforestation has climbed sharply since 1998 (Figure 3–2). The result has been an increase in forest cover from 8% in 1949 to 18.2% in 2003.

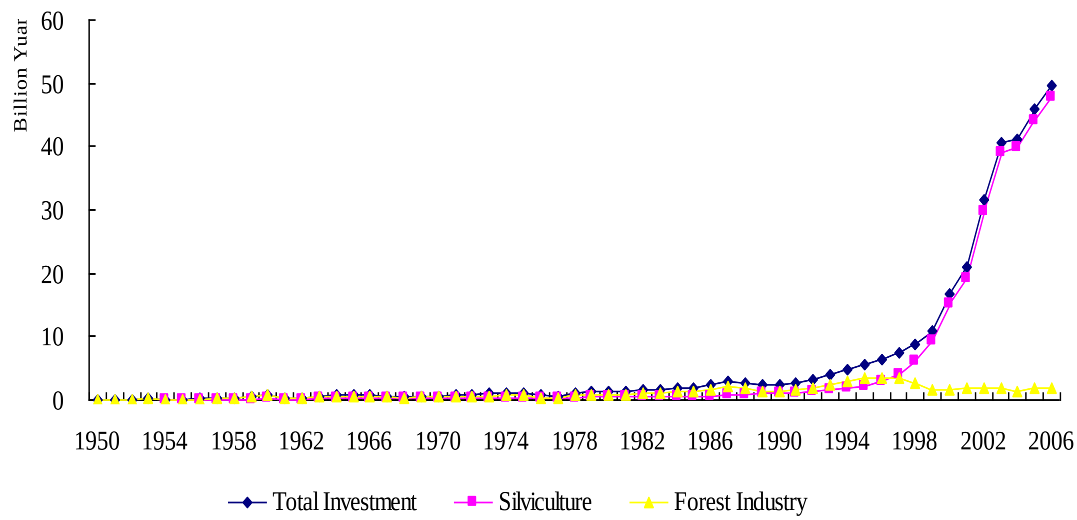

Figure 3-2. Fixed-asset investment in forestry since 1949 in China. (Source: Adapted from data presented in the annual State Forestry Administration reports 1993–2006).

Expansion of the wood industry: Timber production levels were increased sharply during the Great Leap Forward (1958-1961), and climbing during Cultural Revolution (1968–1978), and then increased sharply again after the second forest ownership reform in 1983-1988. During 1990–1998, prior to the occurrence of the catastrophic flooding that triggered the ban on the logging of natural forests (Figure 3–3) the timber production reach historical record. The wood-based panel industry grew gradually from 1984, experiencing marked fluctuations associated with changes in ownership between 1994 and 1998, and in recent years has increased sharply.

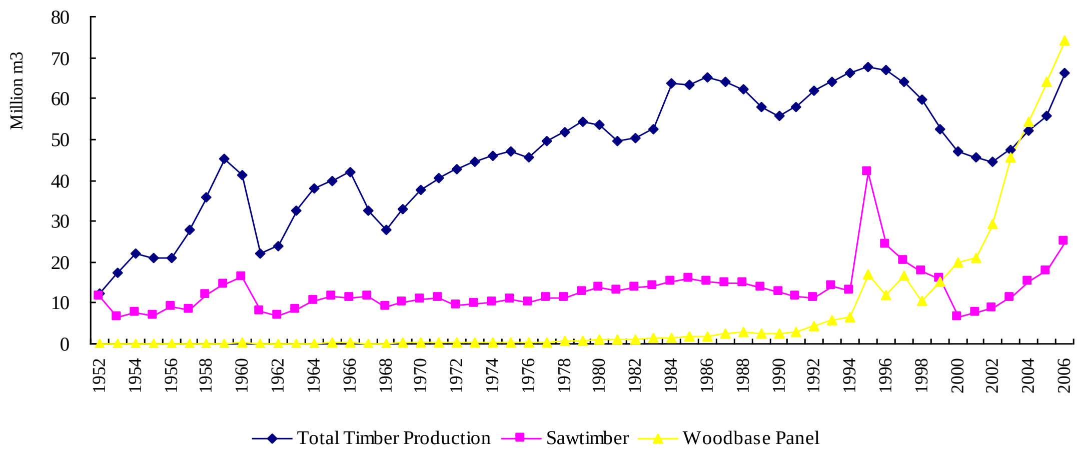

Figure 3-3. Annual production of timber in China since 1952. (Adapted from data presented in the annual State Forestry Administration reports 1993–2007).

Growth in the wood trade: China is now a global manufacturing centre for wood products, benefiting from low labour costs, modern technology and the integration of wood from all over the world. The high-tech and low-cost wood products have successfully penetrated the North American market. The development of short-rotation, high-yield forests is posing a threat to the North American wood industry, and has already impacted the U.S. wood manufacturing sector. In 2007, the forest products trade in China was worth US$ 64.29 billion, a 36% increase over 2006. Forest product imports were valued at $32.36 billion and exports at $31.93 billion, 33% and 21% increases on 2006, respectively (State Forestry Administration, 2008) (Figure 3–4). China has switched from being a net wood importer (based on value) in 1993 to a net wood exporter in 2006. However, on a volumetric basis, there is still a substantial deficit, with net imports of around 86.32 million m^3 of wood products in 2007.

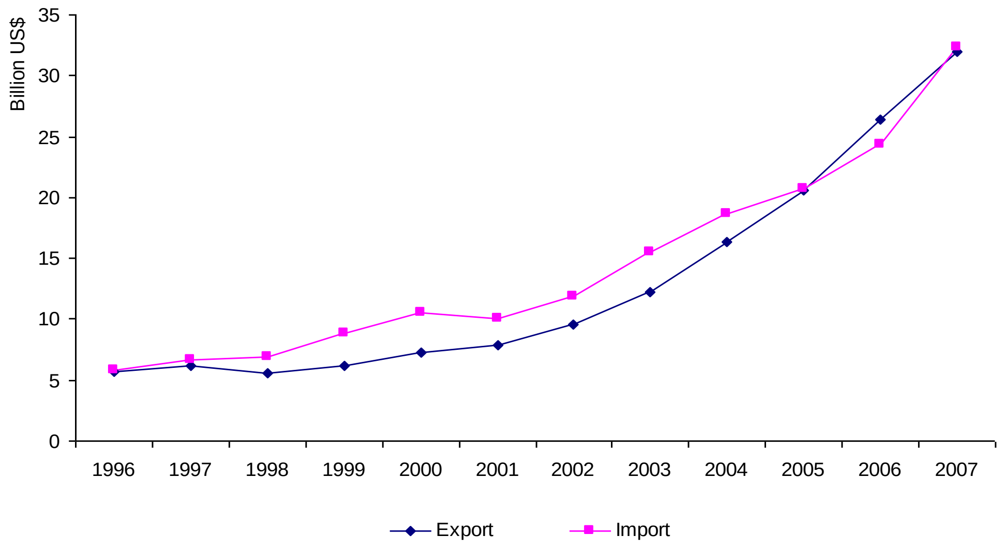

Figure 3-4. Import and export of wood products since 1996. (Adapted from data presented in the annual China Forestry Statistical Yearbooks 1997–2008).

Increases in forest cover. Forest cover has increased since the founding of the People's Republic of China in 1949. During the Great Leap Forward, large-scale harvesting led to the replacement of high quality forests and old growth by plantations. At the same time, there was large-scale afforestation of barren lands, which occurred with minimal seed selection or other attempts to ensure the quality of the resulting plantations. As a result, large-scale, low-quality monocultures were created. During the Cultural Revolution, afforestation was promoted by the Social Campaign, and again the quality of the forest was poor (Research Group of Sustainable Forestry Development, 2003). The implementation of the SKFPs has led to a forest development strategy that has focused on timber production forest, primarily high yield and fast growth, and ecological forest. The Chinese government is looking at ways to restore the forest cover to the levels present in the 18th century by the mid 21st century, a figure that is widely believed to be about 26% (Research Group of Sustainable Forestry Development, 2003).

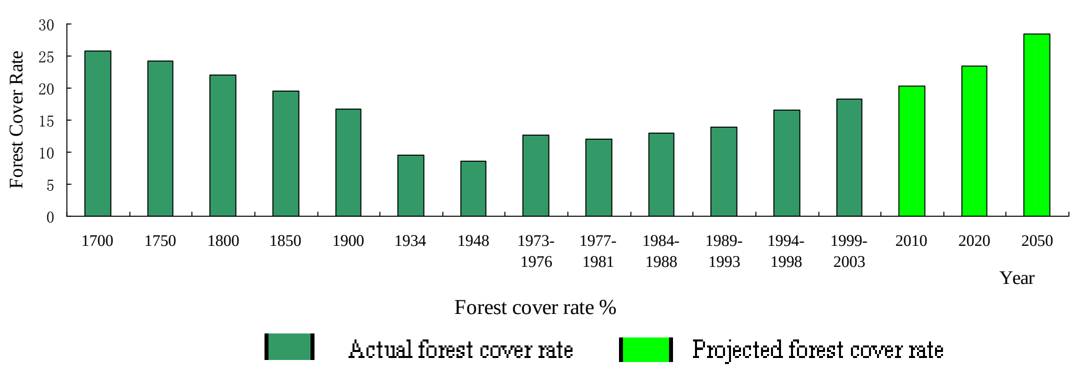

Figure 3-5. Actual and predicted forest cover of China, 1700–2050. (Adapted from He et al., 2007, and data presented in the annual reports of the State Forestry Administration 2000–2006).

3.3 MAJOR ISSUES AND CHALLENGES

3.3.1 China's demand for wood

Rapid economic growth, increased capital investment from both domestic and foreign sources (Li, 2007) and an increase in personal consumption have facilitated construction and housing development, driving up demand for wood products in China. China's demand for roundwood in 2005 exceeded its domestic supply by more than 26 million m^3 (Flynn, 2007). China relies on imports to meet 20% of its industrial roundwood needs, with wood imports increasing annually by 26% over the last 10 years (Figure 3–4), and there is no indication that this rate of growth will abate (Zhang and Gan, 2007). China's demand for wood is driven largely by its growing exports of wood products and the demand for furniture and interior decorations to furnish new construction. In a short time it has developed a significant forest industry based on advanced technologies and low labour costs, enabling it to become an increasingly effective competitor in global markets. Together with its wood-based panel sector, the Chinese furniture industry has accelerated since 1998 and has quickly penetrated and captured nearly 50% of the US market (UNECE Timber Committee, 2006), emerging almost overnight from a near-negligible market share in 2000 (less than US$ 1.5 billion) to US$ 13.18 billion in 2005 (Figure 3–5). The sector is showing evidence of innovation in relation to products, processes and business systems, further enhancing its competitiveness (e.g., Li, 2003; Zhu, 2003; Castaño, 2004; Cao and Hansen, 2006). The availability of low-priced Chinese wood products is leading to trade disputes with the USA and Europe, a problem that forest scientists in China have anticipated (see, for example, Liu and Song, 2005). China's international wood products trade in 2007 reached US$ 64.3 billion, and for the first time since 1993 there was a reverse from being a net importer (based on value) to a net exporter in 2006. However, on a volumetric basis, there is still a substantial deficit, with net imports of around 86 million m^3 of wood products in 2007 (Figure 3–4) (SFA, 2008).

China's wood shortage is not likely to improve soon and other materials, such as agricultural straw (Zhou and Mei, 2000), are unlikely to meet the deficit in the short-term. In 1998, in an attempt to curb disastrous flooding, China imposed a ban on the logging of natural forests in the major headwaters of the Yellow, Yangtze and Songhua Jiang Rivers (e.g., Shen, 2003; Schröder and Zhang, 2007). Since then, domestic wood supply has dropped annually to around 6–8% of wood production (SFA, 2003–2006), while consumption has shown a dramatic increase. As a result, China has increasingly sought wood from outside the country (Sun *et al*., 2004), making the industry vulnerable to external pressures.

China's dependency and vulnerability on wood imports is most obvious with regards to Russia, which is the single largest supplier of logs to China (Flynn, 2007; Song *et al*., 2007) and which has recently introduced a substantial export tax on logs. In addition to the 19 million m^3 of declared wood exports to China, significant volumes of illegally harvested wood from the Russian Far East are also imported. The introduction of wood export taxes by Russia is specifically intended to limit log exports to China and to stimulate the domestic processing of timber. If Russia fully introduces the proposed tariff, there will be significant impacts on the ca. 1000 wood processing manufacturers located along the Russia–China border and the 15,000 Russian wood export companies involved in the cross-border trade. Current annual wood production in Russia is 144 million m^3, but the domestic demand is only 91 million m^3. A lack of infrastructure and advanced technology are still major barriers for the Russian wood-processing industry, and while there have been various attempts to predict likely effects using modelling (e.g., Northway and Bull, 2007), the impacts of the tariff on the trade of logs across the Russia–China border are difficult to foresee.

Southeast Asia has also been a major source of hardwood imports for China ((Sun *et al*., 2004), although wood imports from the region have declined in recent years. Declared exports of wood from Indonesia to China were 1.14 million m^3 in 2001. By 2005, this had declined to 50,000 m^3 due to the introduction of forest protection policies in Indonesia (Zhang, 2007). Malaysia is also a major source of timber for China, but declared imports from this source have declined from 2.93 million m^3 in 2000 to 1.86 million m^3 in 2005. The Philippines formerly exported 80% of their total wood production and the country was one of largest wood exporters in Southeast Asia. However, wood exports have decreased dramatically, from US$ 73 million in 1991 to US$ 24 million in 1998. Meanwhile, illegal exports reached as high as US$ 800 million annually in the mid-1990s (Zhang, 2007). The rising costs of international shipping (by almost 50% since 2003) for wood products (Qin, 2005) is another factor that has forced a switch from sourcing softwood from New Zealand, Australia and Chile to Russia, and from sourcing hardwood from Indonesia and Malaysia to Cambodia and Myanmar.

China recognizes that many of its export markets are increasingly demanding that forest products be certified as coming from sustainably managed forests. While some significant markets, such as certain major purchasers in the USA, are still open to low-cost, uncertified products, increasingly, certification is seen as an important step in maintaining international market access. At the same time, the rapidly increasing sophistication of the Chinese market is creating the possibility for a future demand for certified wood products in China, something the Central Government will encourage (State Forestry Administration, 2006). Currently, China has a national certification standard for forest management and is seeking endorsement of this standard from the international Program for the Endorsement of Forest Certification. Despite the scepticism of some outside observers (e.g., Stone, 2006), it seems likely that this standard will result in significant improvements to forest management practices in China.

It is clear that if the development of the wood industry is to be sustained, China will not be able to rely on large-scale imports of wood. It will have to develop its own fibre sources, and will need to do so through land-tenure reforms and the revitalization of its domestic forestry sector. It will have to develop products that meet the steadily increasing expectations of the market, particularly in relation to environmental performance.

3.3.2 The urgent need for restoration strategies

Serious environmental problems (such as flooding, soil erosion and drought) have been associated with the logging of natural forests and their conversion to other forms of land use (e.g., Hu *et al*., 1999; Wu, 2001; Lu and Yang, 2002; Fan *et al*., 2003). Over 40 large-scale sandstorms have affected China since 2000, including one that is estimated to have deposited 300,000 tonnes of dust over Beijing (China Daily, 2006); such storms are associated with significant health risks (Meng and Lu, 2007). One-third of the urban population is exposed to heavily polluted air, with the incidence of respiratory diseases being clearly linked to pollution levels (e.g., Qian *et al*., 2007; Wang *et al*., 2008c) from pollutants such as sulphur dioxide and nitrogen oxides, and populations in some areas being exposed to rarer atmospheric pollutants, such as arsenic (Hong *et al*., 2007). Smog has become a ubiquitous feature of most major Chinese cities. While the Yangtze River has had 53 major floods in the last 500 years, in the last 50 years, major floods have occurred every three years (Jiang, 2003). Major floods have occurred nearly every year since 2001 and, in the summer of 1998, more than 3000 people were killed and 14 million left homeless. At the same time, the area affected by drought has been increasing (Jiang *et al*., 2005), and a total of 25 million ha. of arable land is affected by drought annually, three times the area affected in the 1950s. Associated with this, there are now 356 million ha. of eroded land in China (Jiang, 2003).

In response to these serious environmental threats, China introduced five key forestry programs related to conservation and ecosystem restoration: the Natural Forest Protection Program (NFPP), the Conversion of Cropland to Forest Program (CCFP), Three North Shelterbelt Development Program and the Shelterbelt Development Program along Yangtze River Basin (3Ns&YRB) and the Sand Control Programs for Areas in the Vicinity of Beijing & Tianjin (SCP). Since 1998, these programs have yielded substantial results, playing a significant role in improving the ecological situation in China, facilitating agriculture and rural development and increasing the income of farmers (Wang *et al*., 2008a).

3.3.3 The structure of forestland ownership

Forest land-use reforms present a major barrier to the rational development of China's forest estate. Ambiguous forest ownership regulations during a period of rapid entrepreneurial activity have resulted in the expropriation of farmland and destruction of forest resources by commercial operations, leading to a sharp rise in land disputes. Unclear land management rights and the inability to exchange forest assets for other assets have discouraged farmers from planting trees and managing forests. Uncertainty about the future of logging policies has reduced the motivation of local people to invest in forestry (Liu and Wang, 2000).

The results of a 2007 joint Task Force involving six Central Government departments that examined the impact of land-use reforms on Jiangxi province (Six Joint-Departmental Investigation Task Force, 2007) provide an indication of the extent of the changes. They found that the reform has brought increased prosperity to rural areas in the province and that forest management practices have improved. The average price of barren land has risen from US$ 31.1 ha^{-1} to US$ 92.4 ha^{-1}. The average price for a young (between 1 and 10 years old) plantation of Chinese fir has risen to US$ 1951.9 ha^{-1}, double what it was at the start of the tenure reforms. The average annual cash income received by farmers from forestry has increased by 44.2%, and now amounts to US$ 26 per person. Between 2004 and 2005, the incidence of crimes related to forest ownership, such as illegal logging, declined by 45%. The number of forest fires and burned areas dropped by 56% and 74%, respectively, in the same period, and the ownership reforms stimulated a major population shift, with 281,000 farmers returning to the land to practise forestry in this single province. In 2006, 220,000 ha. of forest were planted, with farmers and private companies being responsible for 82% of the planting, and the financial investment in forestry from private sources amounted to US$ 62.5 million. Such changes and figures are unprecedented in the history of Jiangxi (Liu, 2007b).

From the few other studies that have been conducted (e.g., Wan *et al*., 2006; Liu, 2007b; Sun, 2007), the results of the tenure reforms seem promising. However, ownership reforms involve a number of different stakeholders, and the diverse interests of the different parties have been difficult to balance. A number of issues are now being addressed.

While implementing the six key forest projects, the national and provincial governments have been subsidizing local farmers by providing annual compensation to those giving up land. In some regions, up to 70% of the forest area has been zoned as ecological forest, with very limited economic activity (e.g., the harvesting of bamboo) permitted. However, as a result of the ownership reforms and the increased financial returns of commercial forests, local people are now reclaiming their forest land (Six Joint-Department Investigation Task Force, 2007).

Prior to these latest reforms, China had conducted four separate land reforms (Wang *et al.*, 2008a). The last reform in particular introduced a great deal of uncertainty over land ownership, and had the unintended consequence of facilitating the spread of illegal logging. It was therefore abandoned before completion. However, because the reform was incomplete, there are now inadequate records of land ownership, and consequently new land-use conflicts have arisen.

If forest lands are to be successfully introduced to the market place, accurate estimates of the forest estate and of forest land values are crucial. However, there has been no legislation introduced to regulate the evaluation of forest land, its transfer or its registration. Additionally, the complexity of forest stands and landscapes, a lack of skilled personnel, and high charges for evaluation services all appear to have hindered the process.

The ownership reforms have greatly increased the number of individuals with a direct link to the land (Six Joint-Department Investigation Task Force, 2007). However, as a result, the ownership of forest land is now highly fragmented. The average area of land allocated to an individual is less than 1 ha, and in areas where the allocations have all been taken up by individuals, it will be very difficult to undertake any form of landscape-level planning. The fragmentation is also leading to changes in land use, such as conversion of forest land to agricultural use or fruit orchards. To be effective, sustainable forest management or the related ecosystem-based management requires a minimum area of forest that is generally larger than the land parcels being allocated under the reforms (Wang et al., 2008a).

3.3.4 The plantation program

Although China has the largest area of plantation forest in the world, accounting for 28.7% of the world's plantations (SFA, 2006; FAO, 2007), it still falls far short of its timber needs. In the period 2001–2007, 5.55 million ha. of commercial forests were established nationwide, including 0.357 million ha. of fast-growing, high-yield timber plantations (SFA, 2008). China's plantation estate now exceeds 53 million ha, 30% of the total forest area in the country. However, less than 10% of this is at harvestable age, forcing the wood processing sector to rely heavily on imports, which reached 121.46 million m^3 of wood in 2007 Wood consumption per capita in China is 0.12 m^3, only one sixth that of the global average, and yet, if this were to be raised by just 0.1 m^3, the demand for wood would increase by 130 million m^3 (Jiang, 2003). Despite all efforts, the Chinese population is still growing by 12 million a year and is projected to reach between 1.2 and 1.6 billion by 2050 (United Nations, 2007).

The 'Forest Industrial Base Development Program in Key Regions with a Focus on Fast-

Growing and High-Yielding Timber Plantations' (FIBDP) was established in 2001 to meet the growing needs of the wood industry. With plans to establish 13 million hectares of fast-growing, high-yield timber plantations, it is likely the program will play a major part in meeting China's future fibre needs (SFA, 2006). However, as it is the only one of the major forestry programs with little government subsidy, progress has been relatively slow. Only 0.19 million ha. have been planted through this program, and the plan has only achieved afforestation over 3% of its planned area (SFA, 2006).

Three measures have been implemented in an attempt to attract private investment and to motivate farmers to practise forest management. On January 1st 2006, China repealed its agricultural tax and the special agricultural products taxes. This has reduced the taxes on wood products to 33%. The Central Government has removed the forest species product tax (representing a sales tax of 10%), and local governments have removed all provincial taxes and some fees (SFA, 2007).

A second approach has been to modify the restrictions on commercial forest harvesting. A pilot study is currently taking place in four counties in the provinces of Fujian, Jinlin, Jiangxi and Yunnan. It is already apparent from this study that fast-growing, high-yield plantations on flat land or on agricultural land should be considered as agricultural crops rather than as forests. This would reduce or eliminate many of the obligations associated with the management of forests.

The third approach has been the establishment of a forest asset marketing system that allows the transfer and trade of forest land. The system consists of a forest and forest land registration centre, a forest resource evaluation centre, a timber and bamboo exchange centre, a forest legal and technical services centre, and a forest labour training centre (Wang et al., 2009).

Studies inside China (e.g., Wan *et al*., 2006; Sun, 2007) have indicated that the success of the afforestation programs will largely depend on the manner in which the forests are established and managed, including the selection and mix of species, site selection, planting density and long-term ecological management (e.g., water issues). In eastern China, especially in the floodplains of the Yangtze Zhu, Min and Qiantang Rivers, large areas of former arable land have been planted with hybrid poplar and eucalyptus, leading to potential outbreaks of pests and diseases. For instance, poplar plantations have already been adversely impacted by the Asian longhorn beetle (*Anoplophora glabripennis*), and a population explosion of this species would be devastating (Baker, 2006).

Much of the afforestation that has been completed through the key programs has been aimed at alleviating immediate problems, including the reduction of soil erosion and the alleviation of shortfalls in domestic fibre supplies. However, there are wider implications for the ecosystem which have not been fully assessed. In particular, the afforestation of large areas is likely to have significant implications for water supply in some areas, and average water yield reductions could be as great as 50% in the semi-arid Loess plateau areas (Sun *et al*., 2006). In such areas, an effective strategy to encourage afforestation has been the prevention of grazing (Peng *et al*., 2006). However, this has implications for local farmers, and suitable alternatives must be identified for the farmers.

Even with such ambitious plantation programs, it is unlikely that China will be able to provide sufficient domestic timber to feed its wood processing industry, leaving it reliant on timber imports. Zhang *et al*. (2005) have estimated that the demand for wood will reach between 214 and 240 million m^3 in 2010, 400–430 million m^3 in 2030, and 574–719 million m^3 in 2050 (these are considered to be conservative estimates, but may be more realistic given the recent economic downturn in China's export markets). The plantation area is expected to reach 53 million ha. in 2010 and 154 million ha. by 2050. The fast-growing plantations in the south are expected to mature by 2015, gradually increasing the domestic wood supply. They estimate that domestic wood supply will increase to 400 million m^3 $year^{-1}$ by 2030, although there is evidence that this may not be achieved.

The continued flow of raw materials into China has implications beyond its borders. Not only are other countries finding it increasingly difficult to compete for timber, but a significant portion of China's log imports are from developing countries (such as Indonesia and Myanmar) with weak regulatory structures(Wang *et al*., 2008b), thus raising serious concerns about importation of illegally logged timber. While the Central Government has imposed import restrictions such as a ban on logs from Myanmar (Wang *et al*., 2008b), it remains unable to effectively monitor and prevent illegal log trafficking. Corruption, both within China and in the source countries, makes combating this problem a very difficult challenge. Some internet-based sources (such as Global Timber: http://www.globaltimber.org.uk/) estimate that significant proportions of China's log imports are illegally sourced. Environmental organizations, especially international watchdog groups, will continue to put pressure on the Chinese government to strengthen oversight of log imports, but as long as provincial and local authorities place greater emphasis on economic development than environmental protection, it will be difficult for the Central Government to control this issue.

3.3.5 The impact on China's rural poor

Land ownership reforms, the development of renewable natural resources and the development of a significant wood industry are objectives intended to contribute to rural community development. However, while China has invested billions of dollars in programs designed to alleviate poverty, living standards are actually decreasing in some areas (State Forestry Administration, 2008). In China, 16.6% of the rural population have an income of less than US$ 1 a day in 2006. It is estimated that natural disasters, environmental protection and economic development have displaced 2.5 million people and an additional five million are likely to be displaced in the near future (Chen and Qin, 2006).

Rural development is still a delicate issue for the modern Chinese economy, and is also an issue when considering social stability and environmental protection. While many urban dwellers in China are enjoying the benefits derived from the "Gai ge kai fang" ("change the system, open the door") policies, the benefits have not fully extended to those living in rural areas. Years of fighting poverty have resulted in marked improvements, with the number of people living in 'dire poverty' (defined in China as an income of less than US$ 0.22 a day) being reduced from 250 million 1978 to 23.65 million in 2005 (Han and Zhao, 2007, and statistics issued by the State Council Leading Group of the Office of Poverty Alleviation and Development). In 2006, this figure was 21.48 million, and the Chinese Government is seeking to reduce it to zero by 2010 (Chinese People's Political Consultative Conference, 2007). Yet the rural poor continue to suffer disproportionately from the effects of environmental degradation, with an estimated 90%

of rural people living in areas suffering from land degradation (Asian Development Bank, 2003). Over 312 million rural residents have no access to safe drinking water (World Bank, 2007) and the media commonly reports on industrial accidents releasing pollutants into the water, leading to violent clashes over polluted water supplies (e.g., China Daily, 2005). Some congress representatives have therefore called for the establishment of an environmental court system in China (China.org.cn, 2008). In 2004 alone, the Chinese government reported some 87,000 "mass incidents" of unrest, or about 240 per day (Keidel, 2006).

The government is attempting to alleviate rural poverty and improve forest management by compensating rural people for the environmental services provided by managed forests (He, 2006). The program started with provincial pilot studies in Fujian and Guangdong in 1999. In 2001, the Central Government approved the concept of providing financial compensation for ecological forests, and the Ministry of Finance set up the necessary funding and administrative procedures. That same year, the Central Government provided RMB 1 billion to conduct pilot studies across 11 provinces, including 685 counties and 24 national natural reserves. In 2004, the Central Government formally delineated 26.7 million ha of forests as key national ecological forests and provided about US \$37.5 ha^{-1} yr^{-1} for 8 years. Local governments followed suit and delineated local ecological forests. In the period 2000–2005, the Chinese Central Government invested over RMB 10 billion, and 3.6 million families, involving 20 million people, have directly benefited from the program (Qi *et al*., 2007).

The program marks the first time that the government has recognized that the ecological benefits derived from forests are directly linked to the contributions that local farmers make in environmental protection. The compensation has enhanced the income of farmers, particularly in remote mountain areas. Combined with the financial payments derived from NFPP and CCFP programs, forests are now contributing significantly to farmers' living standards and the reduction of rural poverty. However, there have been many issues associated with the implementation of the program.

One major problem is that the current level of compensation is too low (￥75 RMB ha^{-1}), covering only 50% of the actual protection and management costs (State Forestry Administration, 2003-2006). This has encouraged forest owners to view the payments as being for forest protection rather than silviculture, yet active management of these forests is required if their full benefits are to be realized. The relevant forest law actually states that the "Forest ecological benefit compensation fund is established for forest resource management, planting, cultivating, and protection", so the compensation program is insufficient to enable the legal requirements to be met. Although the program generally has two beneficiaries, namely the forest owners and local forest rangers, in some areas, the payments have been used exclusively to cover the costs of the forest rangers, with forest owners receiving nothing. Another problem is that the government subsidy does not always go directly to farmers or managers, and local government has been intercepting the payments and deducting a proportion to cover its 'administrative' costs (Six Joint-Departmental Investigation Task Force. 2007).

Some local governments have forced farmers to give up their timberland so that it can be used for local key ecological forests, and have given no or absurdly low levels of financial compensation. This is having a significant impact on the willingness of local people to practise sustainable forestry, and can be interpreted as a failure in the current implementation of sustainable forest management (Wang *et al*., 2008a). In the same vein, many areas have allocated too much forest to protection, leaving farmers with an inadequate land base for survival. The ambiguity of land tenure regulations has also created legal loopholes that allow local governments to take farm lands at very low compensation levels in the name of 'public interest projects,' with the lands then being transferred to commercial interests at great profit to local government (Han, 2005).

3.4 THE ROOTS OF THE ISSUES

China is making major efforts to resolve forest-related environmental, social and economic problems. However, as illustrated above, it still faces many issues and challenges. The current imbalance between economic growth and environmental protection is a direct result of past policies that favour economic expansion over the environment. Many of the issues that the country faces today can be traced to the differing priorities of the many stakeholders that are involved. The Central Government has proposed a science-based approach to development that is designed to both change the current GDP-centered model of growth and realize a balanced form of sustainable development. However, in practice, local governments have failed to achieve this balance, with the economy still being given priority over the environment. It is important to identify the current stakeholders and their main motivation, which will help get to the roots of the issues that are preventing the forest development programs from moving forward. Based on categorizing differences in interests and responsibilities (CAS Sustainable Development Strategic Research Group, 1999 and 2007), there are four main stakeholder groups: (1) the Central Government (2) the local governments, (3) the general public (NGO), and (4) rural residents and forest-dependent farmers. The interests of these groups form the key drivers for the direction in which China's forestry will develop.

Table 3-1 Categories of stakeholder for environmental issues in China

Type of stakeholder	Definition	Explanation
The central government	Agencies and ministries in central government	All organization with statutory and financial powers to develop environment and watershed policy and planning.
Local government	Agencies and departments in provincial, city, and county government	All organization with local level statutory powers and financial benefits from implementing watershed plans and projects
The general public	Professional NGOs and individuals	Professional non-government organizations and individuals who have not direct financial benefit from the watershed management, but have a channel to present their voices and opinions through a public media
Rural residents and forest-dependent farmers	Individual farmers in rural area	Individuals who rely on farming and logging to support their living. And normally cannot have their voice heard (difficult to reach a public media). The protest is a main mean to present themselves.

3.4.1 The Central Government

China is ruled by a communist regime, with the Central Government controlling the financial and political power in the country. The top-down planning systems are still dominated by economic interests. Currently, the Central Government is under internal and external pressure to solve its environmental problems, and is showing an increasing interest in doing so. Its main strategy has been to introduce large-scale programs, such as the Western Development Program and the Six Key Forestry Programs. However, a lack of public participation and consultation that recognises the interests and rights of other parties has hindered the effective implementation of these programs (Guo, 2006; Normile, 2007; Plummer and Taylor, 2004). For example, with the SKFPs, only the NFPP went through pilot studies and coordinated planning. None has gone through any formal public consultation, and implementation has been rushed. Within central Government, there is particular interest in the introduction of a conservation culture (People's Daily, 2007), but this so far has yet to be implemented in any significant way.

3.4.2 Local governments

Local governments, including both provincial and county governments, are the main parties concerned with regional economic development. One of the key indicators for assessing the performance of local officials, and for determining their promotion, is the growth in GDP of their regions. While the implementation of national programs brings federal funding that undoubtedly enhances regional economic development, differences in the objectives of national and local governments mean that the projects rarely meet their intended objectives. Corruption, in the form of diversion of funding for other purposes and false reporting of the projects' progress and achievements, is a major problem. There have been cases where land allocated to ecological forest by provinces was subsequently re-gazetted as commercial forest land for the FIBDP, enabling national funding to be claimed twice (Six Joint-Departmental Investigation Task Force. 2007).

3.4.3 The general public

Environmental problems have become a major concern to the general public (Gleick, 2008)-here mainly are environmental advocates and ENGOs. However, there are no mechanisms that would facilitate public participation or consultation, and the views of the general public are rarely heard in formal ways. Nonetheless, public displays of anger and eruptions of public protest, some of them violent, are increasing (Gleick, 2008; Ma 2009). In a 2006 report, the Congressional Research Service reported that "public order disturbances" had grown 50% between 2003 and 2005 and that the "recent protest activities have been broader in scope, larger in average size, greater in frequency, and more brash than those of a decade ago" (CRS, 2006). Participation by the public in decision-making is weak, partly because the government has been unwilling to allow it (e,g. Wang et al.,2008d), and partly because of a lack of experience and knowledge on the part of the public. The asymmetric availability of information remains a barrier to public awareness and involvement in forestry programs.

3.4.4 Rural residents and forest-dependent farmers

Rural communities are extremely vulnerable, and the farmers often uneducated and poor. The economic reforms that have enabled the emergence of a middle class in China's major cities have also left millions in the countryside without clear land ownership rights or even basic services such as clean water and air (e.g., Han and Zhao, 2007). Despite government reforms, local corruption, unjustified land confiscation and environmental degradation continue to provoke public protests (Han, 2005; Yang 2008). Lacking resources, their interests are often ignored by other stakeholders. The absence of public involvement in the decision-making process and the lack of protection for property rights are key factors blocking progress in the forestry programs (Wang et al, 2008a). Those whose livelihoods are most dependent on forestry find that they have few powers to enforce their land rights, little say in reforms intended to raise their standard of living, and limited recourse to air grievances. For China, it is important to find a solution that addresses the separate and often conflicting needs of this diverse group of stakeholders, otherwise the effectiveness of the forestry reforms will be limited by the underlying inequity of the current system of power.

3.5 CHINA'S FUTURE WOOD REQUIREMENTS

To better understand China's future wood needs, a model that incorporated China's forest availability, economic growth, tariffs, foreign exchange rate, domestic housing market, and wood product competitiveness was used to project the future demand-supply expectations for China. With China's Six Key Forestry Programs, and the tenure reform, China has aggressively developed its own forest in both public and private sectors, with emphasis on short rotation, high-yield forests such as poplar and eucalyptus. As a result, China's wood production is expected to grow over the next twenty years. How much these new forests and plantations will impact China's domestic wood supply is dependent on several factors:

1) Current forest resources and their accessibility over the next twenty years;
2) The increase of commercial forests, particularly the short rotation plantations for industrial fibre;
3) A potential increase in operational harvesting from ecological forests;
4) An increase in the capacity of wood based panels, and paper industry;
5) Changes in demand from Chinese domestic markets in the light of GDP growth; and
6) Development of potential international trade, with consideration of forest certification products.

3.5.1 The projection of China wood products production

In order to further understand the gap between future wood production and consumption in China, the Global Forest Production Model (GFPM) was used to project future wood production, consumption and trade in China. The GFPM, co-developed by the FAO and the University of Wisconsin–Madison, is a spatial equilibrium forest sector model that looks at production, consumption, and trade in forest products at the global level (Buongiorno *et al*., 2003; Zhang *et* *al*., 2007; Zhu *et al*., 2007)[4]. The 2007 version of the GFPM projects world forest commodity markets for 180 countries and 14 different forest commodity categories from a base year (such as 2006) to a target year (such as 2100). For further information about the model, and data sources, please see http://forest.wisc.edu/facstaff/Buongiorno/book/GFPM.htm.

The China Wood Production Model (China Academy of Forestry Planning and Inventory, 2003), which is widely used for AAC determination in China, was used to verify the accuracy of the GFPM Model. Figure 3–6 shows that the GFPM (Model II) projection fell within Scenarios 1 and 2 of the Model I. This suggests that the GFPM provides reliable projections. The following projections are based on the GFPM modelling, as the China Wood Production Model is only available for predicting log production.

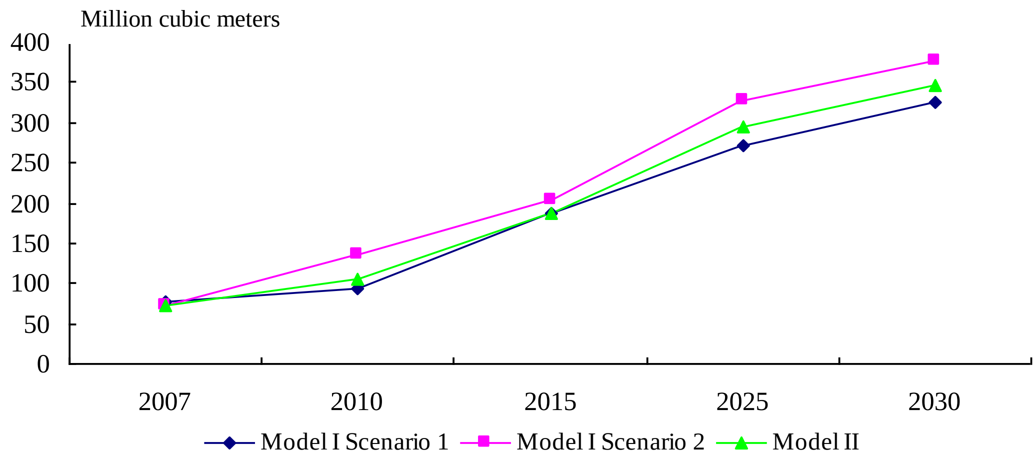

Figure 3-6. Simulation of China's log production under two projection models with three scenarios.

Model I is based on the percentage of fulfillment of SKFP (Scenario 1 is 60% of completion, and Scenario 2 is 90% of completion). Model II is based on GFPM simulation.

The simulation results suggest that Chinese wood production will keep increasing over the next 20 years (Figure 3–6) due to the maturation of new plantations. The supply of logs and veneer will increase dramatically, while sawn lumber, plywood, particleboard and fiberboard will grow more gradually over the next 20 years (Figure 3–7). The production of pulp and paper will also increase, particularly paper production (Figure 3–8).

[4] For more detailed information, please see http://forest.wisc.edu/facstaff/Buongiorno/book/GFPM.htm)

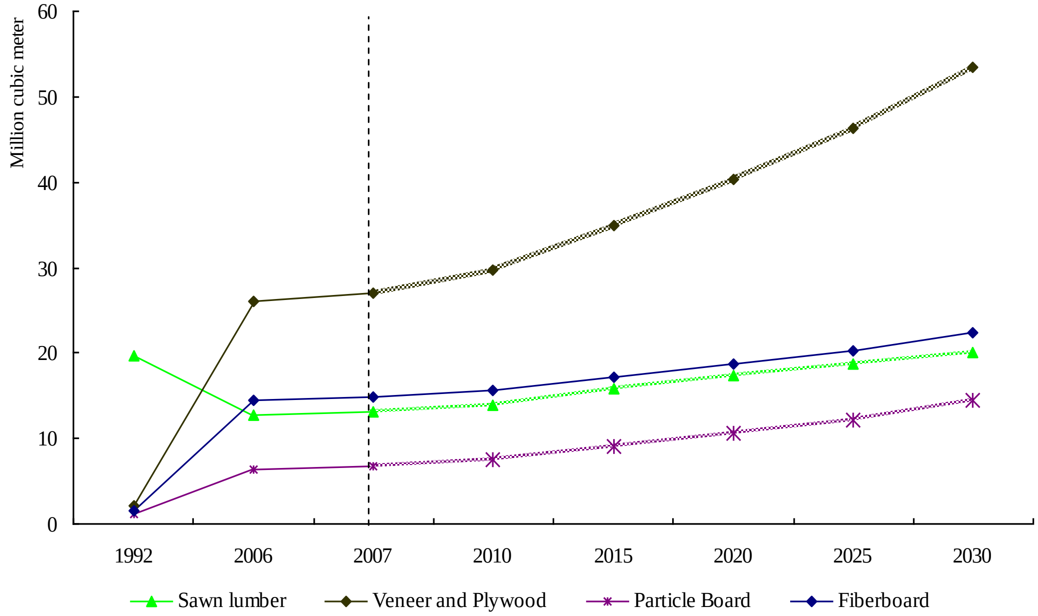

Figure 3-7. Projection of China's wood-based panel production over the next twenty years.

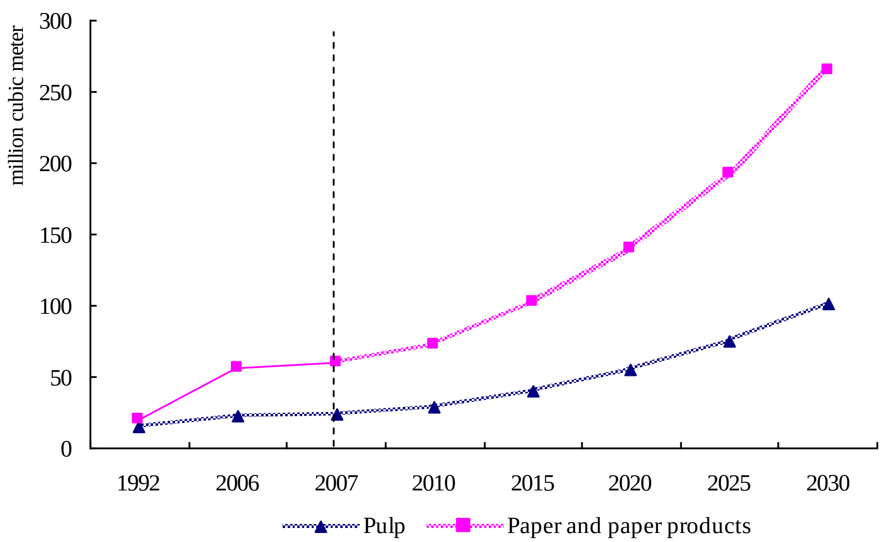

Figure 3-8. Projection of China's pulp and paper production over the next twenty years.

3.5.2 The projection of China's consumption and trade deficit

The projection also suggests that the demand for wood products over the next twenty years will remain strong (Figure 3–9). The demand for logs will dominate Chinese forest imports over the first ten years, with the volume of log demand being larger than the other four products combined. Sawn lumber is China's second most in-demand forest product and its growth will increase over the next twenty years. The Chinese demand for wood has triggered protective measures in neighbouring countries, such as Russia, which has increased its export tariffs in an attempt to limit log exports to China. Many Southeast Asian counties are implementing log export quotas in attempts to reduce timber exports.

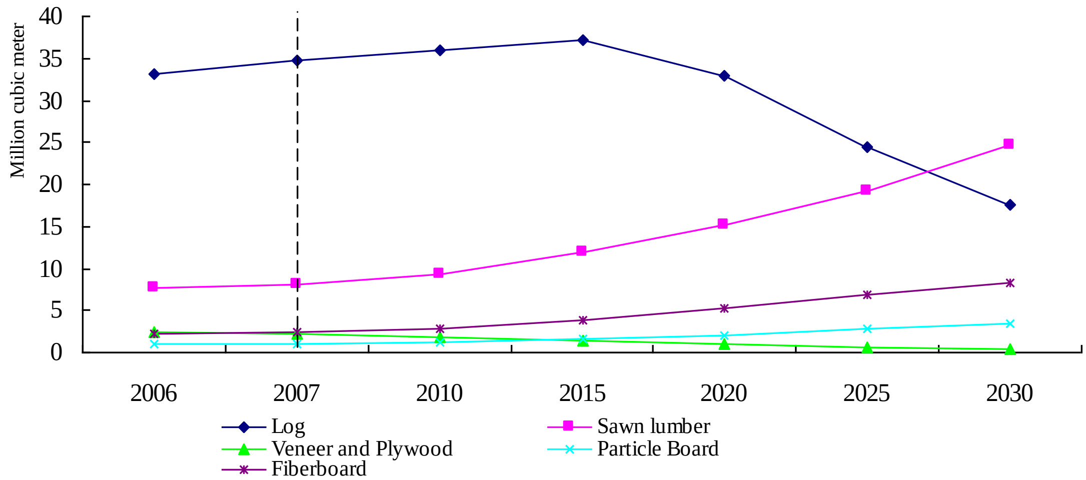

Figure 3-9. Projection of China's imports of wood products over the next twenty years.

China's demand for pulp, paper and paper products will likely increase in the long term as Chinese paper production and consumption per capita in 2006 was
41 kg $year^{-1}$, lower than the world average of 52 kg $year^{-1}$, and far lower than the average for major developed countries (300 kg $year^{-1}$) (State Forestry Administration, 2007). It is generally believed that China will gradually catch up with world average (Table 3-10).

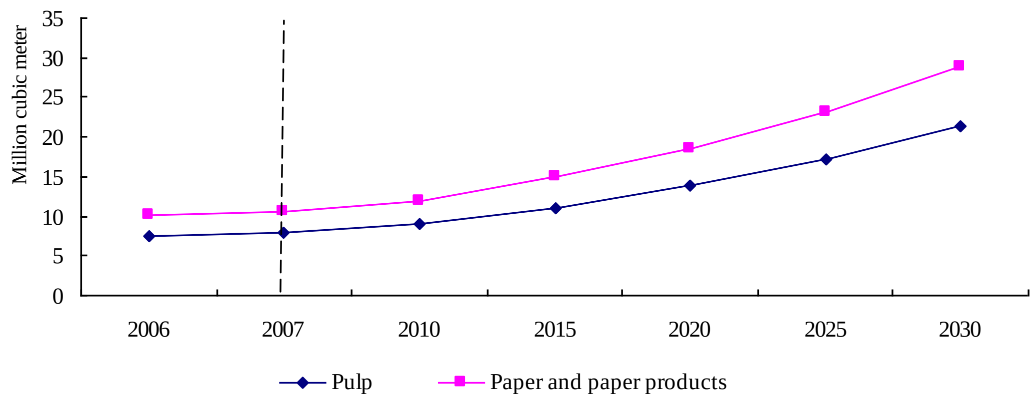

Figure 3-10. Projection of China's imported pulp and paper products over the next twenty years.

A summary of the simulation results (Figure 3–11) indicates the net trade in forest products for China over the next twenty years. China will mainly be in deficit, although the extent will vary by product. With the exception of surpluses for veneer and plywood and a changing trend for logs, all wood products will show steadily increasing deficits.

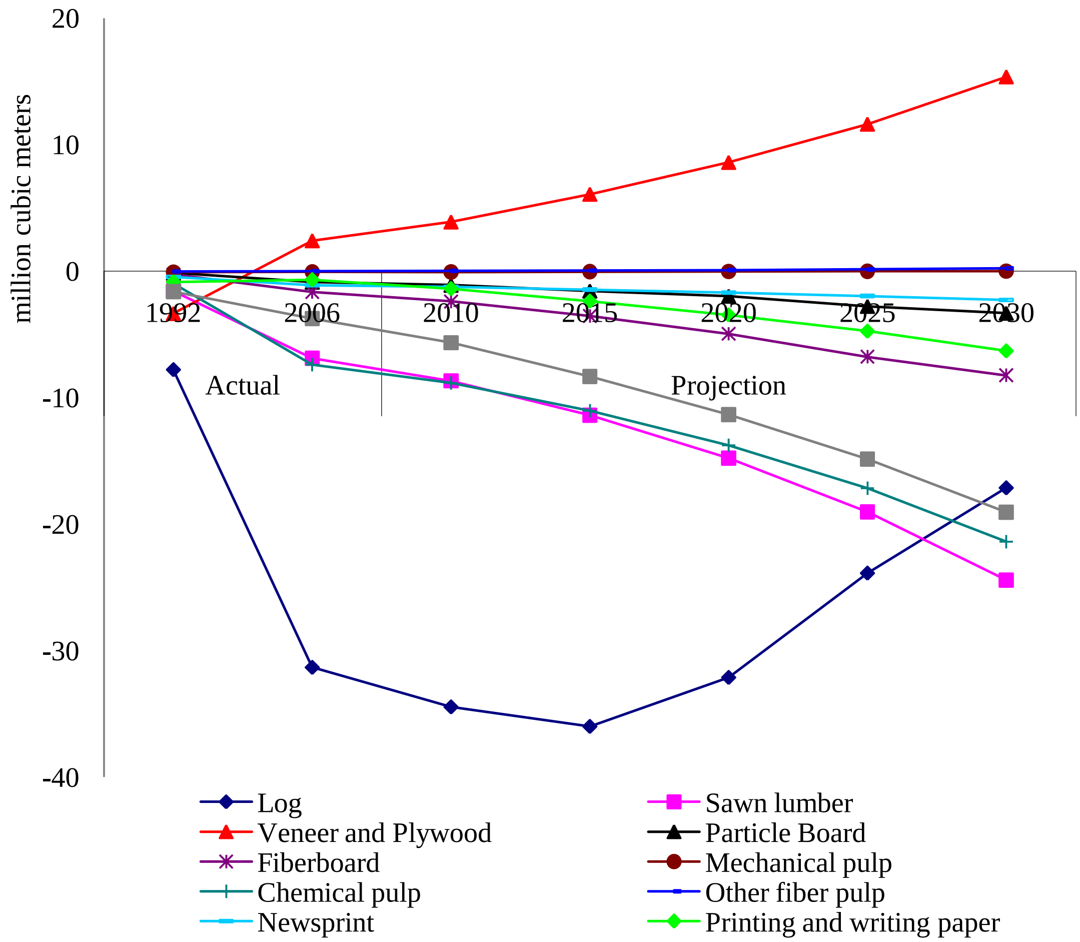

Figure 3-11. China net trade projection over the next twenty years.

3.6 IS THERE A SOLUTION?

China's forestry is currently at a crossroads. It faces enormous problems, but at the same time there is tremendous potential. A comprehensive, well-planned strategy is required that takes into account the complexities of the Chinese situation. The six key forestry programs, ongoing land tenure reform, related policy changes and government support have together set a strong foundation for further development. These opportunities are discussed in more detail in the following sections.

3.6.1 New opportunities for forestry

As indicated above, the Central Government of China is advocating a much more balanced approach to the relationship between the economy and the environment. To date, the emphasis has been on economic development, but this is changing, as indicated by a speech by Hu JinTao in 2007 (People's Daily, 2007). An example of this change in attitude is provided by the Forest Care program, initiated by the Population, Resources and Environment Committee of the National Committee of the Chinese People's Political Consultative Conference (Government of

China, 2008). These changes are part of a longer term trend, described below.

On 11 October 2006, the Central Committee of the Chinese Communist Party approved a new ideological theme—building a “Harmonious Society”—to balance the country’s economic growth with environmental reforms to ensure a stable society. The “Harmonious Society” elevates the sustainability into a national priority, and recognizes that social stability is dependent on a balance between economic growth and improving the environment. The implication is that environmental protection should not fall behind economic growth. In support of the policy, the Chinese government has introduced a series of new development concepts, goals and guiding principles, some of which provide opportunities for forest resource protection and management.

A market-based instrument, termed the Circular Economy (CE), is being introduced to enhance economic and environmental performance through the collaborative management of environmental and resource issues (Bi, 2004; Pinter, 2006). The basic concept involves the transfer of information and surplus materials (including waste products) from one company to another, thereby improving performance (Bi *et al*., 2000). Forestry is ideal for this and should benefit in the areas of forest resource development, agroforestry, wood and energy saving, and community-based forest development. The increase in flexibility and innovation, as well as the testing and adoption of existing and new environmental technologies, should lead to much greater resource efficiency and less demand on the forest for fuel.

Secondly, an opportunity is provided by the Kyoto Protocol Clean Development Mechanism (CDM). This would involve the forest sector working closely with industry to identify and implement compensation mechanisms for ecological benefits. The first CDM project in China was officially launched in January 2007 by the World Bank in Guangxi, entitled the Guangxi Forestry Comprehensive Development and Protection Project. This project was the first afforestation project designed by the World Bank BioCarbon Fund. The total investment involved nearly US$200 million for afforestation of 4000 ha. of barren land (Wang, 2007).

China is also introducing Green GDP and auditing systems that will allow the general public and the government to assess regional development in the economy in relation to the consumption of resources and damage to the environment. It will also enable the environmental performance of local governments to be assessed. Such a change should facilitate a switch away from the current focus on economic development to an approach that simultaneously considers the economy and the environment. Progress has already been made in this area, and on 8 September 2006, the China Green National Accounting Study Report 2004 was jointly issued by the State Environmental Protection Administration and the National Bureau of Statistics. The report, the first ever attempt by the Chinese government to develop an environmentally-adjusted GDP accounting system, is a significant development.

3.6.2 Further reforms

The forest management system in China is one of the last remnants of an economic planning system that focused primarily on resource exploitation and centralized control (Wang et al. 2007). Reform of the forest management structure is now essential (State Forestry Administration,2008). The Central Government has approved the Solution to Further

Implementing Forestry System Reform developed by State Forest Administration in June, 2009 (People Daily, 2009). After the completion of three key tasks, namely reform of forestland ownership, gazetting of commercial and ecological forests and afforestation of barren lands, management policies need to be changed (State Forestry Administration, 2008). Ecological forests should be strictly enforced, and rules for commercial forests relaxed to enable their efficient development and harvesting. Forest managers will be given the freedom to determine the harvest age (based on economic maturity), to apply intensive forest management techniques, to select the most appropriate tree species, to pursue all potential economic benefits, and to harvest according to their needs rather than according to some pre-determined level of cut. Essentially, commercial forests will be managed according to market forces. The government will also relax the rules that prevent regional planners from sourcing private capital, thereby making them less reliant on government subsidies. Most notably, the government will no longer control, but rather encourage, the development of the commercial wood products trade (State Forestry Administration, 2008; People Daily, 2009).

3.6.3 Future forestry plans

Looking forward, the State Forest Administration has set a new goal to position forestry as an important player in China’s social, economic and environmental development. One of the key indicators is that the forest cover should be increased to 26% by 2050 (State Forestry Administration, 2008a). This is equivalent to the level of forest cover in 1700 (Figure 3–6). A second major policy being introduced by the SFA is to adopt the Clean Development Mechanism to resource development based on renewable resources, recycling, conservation and clean fuels (State Forestry Administration, 2008a).

According to the National Ecological Environmental Construction Development Plan and the 11th Five-year Plan for Forestry, between 2006 and 2010 there will still be a focus on the six key forest programs (Wang et al., 2007). The total investment in the programs in the period will be US$ 65.8 million (Table 3–1) (Forestry, Research Group of Sustainable Forestry Development, 2003). The aim is to establish 77 million ha. of new forest, including 53 million ha. of commercial forest (Wang et al, 2008a). The area of natural reserves will reach 16.1% of China’s land area, and 12 million ha. of land currently affected by severe soil erosion and 3.3 million ha. of sandy arable land will be planted with forest (State Forestry Administration, 2008). The area of fast-growing and high-yield plantations forest will be increased to 10 million ha, which should alleviate the pressure on existing domestic wood supplies. Long-term planning (to 2050) will also focus on the ecological development, stewardship and protection of forests (Table 3–2) (State Forestry Administration, 2008a). Between 2011 and 2050, 147 million ha. of land will be afforested, and 7.5 million ha. of low-value and degraded forest will be improved. A total of 177.3 million ha. of forest will be protected. The investment in forestry between 2000 and 2050 is expected to be around US$ 181.5 billion. Forest protection and stewardship will account for 46.6% of this sum, accounting for more investment than any other activity in the Chinese forestry sector (State Forestry Administration, 2008a). The area of ecological forest will gradually increase while the rate of afforestation will decline throughout this period.

Table 3-2. Planned forest investment in the period 2006–2010. Units are billion Yuan. (Adapted from National Ecological Environmental Construction Development Plan and the 11th Five-year Plan for Forestry, Research Group of Sustainable Forestry Development, 2003).

Item	Investment (2006–2010)	Main activities
Six key forest programs	454	afforestation of 0.5 billion ha
Infrastructure construction	5.2	forest fire protection, maintenance of forest stations, research, education and training
Forest ecological benefit compensation	21.5	payments to farmers for transfer of productive forest land to reserves
Government operation expenses	8.6	forest agency, forest inventory, and monitoring expenses
Other financial compensation	12.3	forest public outreach facility development, tree genetic improvement, national park and conservation development
Compensation for combat desertification	24.8	
Total Investment	52.6	

Table 3-3. Planned forest investment between 2011 and 2015. Units are billion Yuan. (Adapted from National Ecological Environmental Construction Development Plan and the 11th Five-year Plan for Forestry, Research Group of Sustainable Forestry Development, 2003).

Item	2011–2020	2021–2030	2031–2050	
Silvicultural and forest management	174	123	144	Forest ecological development projects
Forest protection and stewardship	163	171	340	Forest ecological benefit compensation program
Forest infrastructure development	81.5	85.7	170	Forest fire protection, disease control and facility construction
Total	418.5	380	654	1452.5

3.7 CONCLUSIONS

China's forests are facing enormous pressure. Since 1998, forestry in China has been experiencing a period of massive change, including the afforestation of barren and steep arable land, the reform of land tenure, the separation of commercial and ecological forests and the development of appropriate support systems. However, the current system of governance is creating a chaotic situation in rural areas, often associated with the breakdown of the social structures of communities.

The Chinese government and general public have gone through a gradual process of recognition of the relationship between development and environmental protection. Now, various approaches to resource development are likely to be adopted, rather than the exclusive focus on economic benefits that has dominated until now. However, there remains a fear that implementing environmentally-friendly strategies could erode the country’s industrial competitiveness, so progress is unlikely to be rapid. For example, implementation of pollution emission standards that meet those of the USA would undoubtedly lead to the closure of many industries in China.

The environmental problems facing China are also affecting other countries, such as global warming, sandstorms, air pollution, water depletion, deforestation and illegal logging. Some of these problems are transboundary in nature – dust from the Gobi Desert has been associated with hospital admissions in British Columbia, Canada (Bennett *et al*., 2006), and air pollutants originating from China have been identified in North America (Jaffe *et al*., 1999; Yienger *et al*., 2000). In 2005, a serious pollution event in the Songhua River not only affected major towns in China such as Harbin but extended downstream, reaching the Amur River and the city of Khabarovsk in Russia (Li, 2006). The economic repercussions of China’s development are also being felt globally: These international impacts suggest that solving China’s environmental problems must be an international effort. Currently many international organizations such as the World Wide Fund for Nature, the Global Environment Facility, the Program for the Endorsement of Forest Certification and the International Tropical Timber Organization are working closely with China to improve its forest management. Such efforts need to continue, in part because China needs the expertise and resources to better manage its forests, and in part because it currently lacks the internal democratic infrastructure that would provide the checks and balances needed to oversee government policies.

3.8 REFERENCES

Asian Development Bank 2003. Fighting poverty in Asia and the Pacific: The poverty reduction strategy. Available at: http://www.adb.org/Documents/Policies/Poverty_Reduction/default.asp. Accessed on 12 March 2008.

Bi Jun. 2004. Development of Circular Economy in China, Presentation at Yale University Industrial Symbiosis Symposium, January 2004. New Haven.

Baker, J. 2006. *Paulownia* intercropping in Heze, Shandong Province: Its past success, current demise, and future potential. Michigan State University. Available at: http://forestry.msu.edu/China/2006/Papers/Jake.pdf. Accessed on 12 March 2008.

Bennett, C.M., McKendry, I.G., Kelly, S., Denike, K. and Koch, T. 2006. Impact of the 1998 Gobi dust event on hospital admissions in the Lower Fraser Valley, British Columbia. *Science of the Total Environment* 366: 918–925.

Bi, J., Yang, J., Yuan, Z. and Huang, J. 2000. *Circular economy: An industrial ecology practice under the new development strategy in China*. Center for Environmental Management & Policy, Nanjing University.

Blomquist.W., Calbick, K. S. and Dinar A. 2005. *Institutional and Policy Analysis of River Basin Management: The Fraser River Basin, Canada.* World Bank Policy Research Working Paper 3525, February 2005.

Brown, L.R. 2006. *Plan B 2.0: Rescuing a Planet Under Stress and a Civilization in Trouble*. The Earth Policy Institute. New York. NY. USA.

Castaño, J. 2004. The booming furniture industry in China. *Bois et Forêts des Tropiques* 279: 85–87.

Cao, X.Z. and Hansen, E.N. 2006. Innovation in China's furniture industry. *Forest Products Journal* 56: 33–42.

CAS Sustainable Development Strategic Research Group 2007. *China Sustainable Development Strategy Report 1999: China Sustainable Development Strategy Design and Planning*. Science Press: Beijing.

CAS Sustainable Development Strategic Research Group 2007. *China Sustainable Development Strategy Report 2007 – Water: Governance and Innovation*. Science Press: Beijing.

Chen, G. J. and Qin, B.F. 2006. Strategic adjustment and management of ecological migration in China (in Chinese). Accessed on 12 March 2008.http://www.sciencenet.cn/html/shownews.aspx?id=166539.

China Daily, June 7, 2005. China says water pollution so severe that cities could lack safe supplies. Available at: http://www.chinadaily.com.cn/english/doc/2005-06/07/content_449451.htm . Accessed 12 March 2008.

China Daily, April 21, 2006. Sandstorm brings heavy damage. Available at: http://english.peopledaily.com.cn/200604/21/eng20060421_260099.html. Accessed on 12 March 2008.

China Academy of Forestry Planning and Inventory. 2003. *China Wood Production Model and application.* China Academy of Forestry Planning and Inventory: Beijing, China

China.org.cn, March, 8, 2008. People representatives Lu Zhong Mei: Calls for establishing environmental court in China (in Chinese). Available at: http://www.china.com.cn/2008lianghui/2008-03/08/content_11999222.htm. Accessed on 12 March 2008.

Chinese People's Political Consultative Conference 2007. Press release. Available at:

http://www.cppcc.gov.cn/English/news/200703070040.htm. Accessed 12 March 2008.
CRS 2006. Social unrest in China. May 8, 2006, Thomas Lum Specialist in Asian Affairs Foreign Affairs, Defense, and Trade Division, *CRS Report for Congress*. Order Code RL33416. Available at: http://www.fas.org/sgp/crs/row/RL33416.pdf. Accessed on 12 March 2008.
Economy, E. 2007. *China's Energy Consumption and Opportunities for U.S.–China Cooperation to Address the Effects of China's Energy Use*. Available at: http://www.uscc.gov/hearings/2007hearings/written_testimonies/07_06_14_15wrts/07_06_14_economy_statement.php. Accessed on 12 March 2008.
Fan, B.M., Dong, Y., Zhang, J.C. and Yin, J.Y. 2003. Effects on flood and drought since the destruction of forests in China: a discussion on hydro-climatic effects of forest. *Scientia Silvae Sinicae* 39(3), 136–142.
FAO 2007. *State of the World's Forests 2007*. FAO: Rome, 144pp.
Flynn, B. 2007. Presentation at 2007 WFI Conference: Who will own the forest: Global series investing globally in forestland. Held on September 10–12, 2007. World Forestry Center, Portland, Oregon, USA.
Gleick, P. 2008. *The world water 2008-2009: the biennial report on freshwater resources.* Island Press,432pp.
Government of China, January 21, 2008. Senior official calls for forestry protection. Available at: http://english.gov.cn/2008-01/21/content_864632.htm, accessed 12 March 2008.
Guo, G.H. 2006. Participatory rural appraisal in the grain to green program. *Forestry Economics* 6, 78–80.
Hamilton, G. 2006, China suddenly the world's top exporter of wood products. *Vancouver Sun*. Published on Wednesday, April 12, 2006
Han, H. 2005. *Deforestation and rural poverty in China: Essences and countermeasures*. China Academy for Rural Development, Zhejiang University, Hangzhou , Zhejiang, 310029, China, 10 pp.
Han, J.M. and Zhao, Y.P. 2007. On countryside poverty in process of Chinese economic growth. *Research of Agricultural Modernization* 28(2), 135–139.
He, F., Ge, Q., Dai, J. and Lin, S. 2007. Quantitative analysis on forest dynamics of China in recent 300 years. *Acta Geographica Sinica* 62(1), 30–40.
He, J. 2006. Payment for environmental services in China: a policy perspective. *ICIMOD, Newsletter of the International Centre for Integrated Mountain Development* 50, 39–41.
Hong, F., Zhang, A.H. and Jin, T.Y. 2007. A study on renal dysfunction of arsenic poisoning victims caused by air pollution from coal burning. *Journal of Environmental and Occupational Medicine* 24(6), 580–583.
Hu, H.B., Zhang, J.C. and Ruan, H.H. 1999. Approaches towards the causes of the formation of and counter-measures for the flood on the Changjiang river basin in 1998. *Journal of Fujian College of Forestry* 19(4), 303–306.
By Turner, J.L and Otsula, K. Institute of Developing Economies (IDE). JETRO.
Jaffe, D., Anderson, T., Covert, D., Kotchenruther, R., Trost, B., Danielson, J., Simpson, W., Berntsen, T., Karlsdottir, S., Blake, D., Harris, J., Carmichael, G. and Uno, I. 1999. Transport of Asian air pollution to North America. *Geophysical Research Letters* 26(6), 711–714.
Jiang, F.Q., Li, Z. and Hu, R.J. 2005. Influences of drought on agriculture and disaster-chain effect during the second half of the 20th century in Xinjiang. *Arid Land Geography* 28(4), 465–473.
Jiang, Z.H. 2003. China's forestry in new century: Sustainable forestry management. *Chinese*

Scientist: 5, 8–12.
Keidel, A. 2006. China's internal unrest. Written testimony before the U.S.–China Economic and Security Review Commission Hearings on Major Internal Challenges Facing the Chinese Leadership, U.S.–China Economic and Security Review Commission, February 2, 2006. Available at: http://carnegieendowment.org/files/Keidel_Social_Unrest.pdf. Accessed on 12 March 2008.
Li, F. 2007. Study on the impaction of foreign investment on forestry product trade and the strategy. *World Forestry Research* 20(4), 63–66.
Li, W.L. 2003. Theoretic analysis on enforcement of CRM system in furniture businesses. *China Wood Industry* 17(5), 22–24.
Li, W.X. 2006. Looking at the Songhua River incident from an environmental regulatory governance perspective: a long standing issue in China. *Perspectives* 7(1), 21–35.
Liu, J.L. 2007a. Contextualizing forestry discourses and normative frameworks towards sustainable forest management in contemporary China. *International Forestry Review* 9(2), 653–660.
Liu, L.Z. 2007b. Current situation of the collective forest ownership reform in Jiangxi province. State Forestry Administration (in Chinese). Available at: www.forestry.gov.cn/subpage/content.asp?lm_Tname=n_xwfb&lmdm=1000&f_lmname=%E9%8F%82%E4%BC%B4%E6%A4%88%E9%8D%99%E6%88%9D%E7%AB%B7&id=42. Accessed on 12 March 2008.
Liu, L.L. and Song, W.M. 2005. Discussion about America's taking anti-dumping measures to China. *World Forestry Research* 18(6), 69–74.
Liu, D.Z. and Wang, G.Y. 2000. The impact of WTO entry and countermeasure on Fujian Forestry Industry. *Issue of Forestry Economics*. 20(1):1-4, 8.
Lu, Q., and Yang Y.L. 2002. Causes of sandstorm disaster and strategies against desertification. *Chinese Forestry Science and Technology* 1, 63–72.
Ma, T.J.2009. *Environmental mass incidents in rural China*. China Environment Series Edited by Turner, Jennifer L. Woodrow Wilson International Center for Scholars. Issue 10: 34-48.
McCarthy, M. 2005. China Crisis: threat to the global environment, Spectacular growth now biggest threat to environment. The Independent, 19 October 2005. Available at: http://news.independent.co.uk/world/asia/article320565.ece. Accessed on 12 March 2008.
Meng, Z.Q. and Lu, B. 2007. Dust events as a risk factor for daily hospitalization for respiratory and cardiovascular diseases in Mingin, China. *Atmospheric Environment* 41(33), 7048–7058.
Normile, D. 2007. Getting at the roots of killer dust storms. *Science* 317, 314–316.
Northway, S. and Bull, G.Q. 2007. *Forest products trade between Russia and China. Potential production, processing, consumption and trade scenarios*. Forest Trends, Washington, D.C., 14 pp.
OECD. 2007. OECD Environmental Performance Review of China. Paris, France. Organization for Economic Cooperation and Development.
Plummer, J. and Taylor, J.G. 2004. *Community participation in China: Issues and processes for capacity building*. Earthscan, Landon.
Pan, Y. 2006. *Economic development and environmental protection*. State Environmental Protection Administration of China (in Chinese). Available at: http://www.sepa.gov.cn/hjyw/200612/t20061220_97538.htm. Accessed on 12 March 2008.
Peng, Z.H., Dong, L.S., Zhang, X.D. and Zhou, J.X. 2006. Closing hillsides to facilitate afforestation: An important measure for the vegetation restoration of the loess plateau in China. *World Forestry Research* 19(2), 61–67.

People's Daily, October 15, 2007. Hu Jintao advocates "conservation culture" for first time in keynote political document. Available at: http://english.peopledaily.com.cn/90002/92169/92187/6283133.html. Accessed 12 March 2008.
People Daily, June 23, 2009. Develop forestry industry and promote reform of collective forest rights.. http://paper.people.com.cn/rmrb/html/2009-06/24/content_281416.htm
Pinter L. 2006. International Experience in Establishing Indicators for the Circular Economy and Considerations for China. International Institute for Sustainable Development, 27pp.
Qi, L., Liu, S.Y. and Jia, D.M. 2007. Ecological compensation: the important measure for balancing the regional development (in Chinese). China Green Time. Available at: http://www.ccpef.org.cn/ShowArticle.asp?ArticleID=242. Accessed on 12 March 2008.
Qian, Z.M., He, Q.C., Lin, H.M., Kong, L.L., Liao, D.P., Yang, N.N., Bentley, C.M. and Xu, S.Q. 2007. Short-term effects of gaseous pollutants on cause-specific mortality in Wuhan, China. *Journal of the Air and Waste Management Association* 57(7), 785–793.
Qin, Y. 2005. 2004 China wood import and export market analysis. *Wood Market News* 4, 29–32.
Research Group of Sustainable Forestry Development 2003. *Study on China Sustainable forestry development*. China Forestry Press. Beijing, China (in Chinese).
Richardson, S.D. 1990. *Forests and forestry in China. Changing patterns of resource development*. Island Press, Washington DC, 352 pp.
Schröder, J.M. and Zhang, J.F. 2007. Control of forest degradation at the Yangtze. *AFZ/Der Wald, Allgemeine Forst Zeitschrift für Waldwirtschaft und Umweltvorsorge* 62(11), 604–607.
Shen, G.F. 2003. Forest degradation and rehabilitation in China. *RAP Publication* 14, 119–125.
Six Joint-Departmental Investigation Task Force. 2007. *Investigation Report on Jiangxi Forest Ownership Reform*. State Forestry Administration, Beijing (in Chinese).
Song, W., Cheng, B., Zhang, S. and Meng, X. 2007. *Russian logs in China. The softwood commodity chain and economic development in China*. Forest Trends, Washington, D.C., 37 pp.
State Forestry Administration 2005a. *China Forest Resources*. State Forestry Administration, P.R.China. January 2005 (in Chinese).
State Forestry Administration 2006. *Enhancing forestry ecological improvement and accelerating development of the industry*. State Forestry Administration, P. R. China (in Chinese).
State Forestry Administration 1993–2008. *China Forestry Statistical Yearbook*. Beijing. China Forestry Publishing House (in Chinese).
State Forestry Administration 2000–2006. *China Forestry Development Report*. Beijing. China Forestry Publishing House (in Chinese).
State Forestry Administration 2007 Analysis of China paper industry. Accessed on 12 Nov. 2008. http://www.forestry.gov.cn/distribution/2007/01/15/mcjg-2007-01-15-28.html.
State Forestry Administration 2003–2006. *Social-economic evaluation report on National Key Forest Programs*. China Forestry Publishing House (in Chinese).
State Forestry Administration 2001–2005. *The Six Key Forestry Programs annual progress report*. State Forestry Administration, P.R. China (in Chinese).
State Forestry Administration 2008. *China Forestry Development Report.* China Forestry Publishing House: Beijing.
State Forestry Administration 2008a. *The China's Longterm Forestry Development Plan*. State Forestry Administration.
State Environmental Protection Administration of China (SEPA) and the National Bureau of

Statistics of China 2006. *China Green National Accounting Study Report 2004* (in Chinese). Available at: http://www.sepa.gov.cn/plan/gongwen/200609/P020060908545859361774.pdf. Accessed on 12 March 2008.

Stone, M.W. 2006. China and certification: a questionable future. *Journal of Forestry* 104(6), 332–334.

Sun, G., Zhou, G.Y., Zhang, Z.Q., Wei, X.H., McNulty, S.G. and Vose, J.M. 2006. Potential water yield reduction due to forestation across China. *Journal of Hydrology* 328, 548–558.

Sun, X.X. 2007. Fujian forest-ownership reform on-the-spot report (in Chinese). Chinanews. Available at: http://www.chinanews.com.cn/cj/kong/news/2007/07-06/973437.shtml. Accessed on 12 March 2008.

Sun, X., Katsigris, E. and White, A. 2004. Meeting China's demand for forest products. An overview of import trends, ports of entry, and supplying countries with emphasis on the Asia-Pacific region. *International Forestry Review* 6(3–4), 227–236.

Tuner, J. L. 2006. *New Ripples and Response to China's Water Woes*. Woodrow Wilson International Center for Scholars, China Brief, Volume 6. Issue 25, December, 19, 2006.

United Nations. 2007. *World Population Prospects: The 2006 revision*. Available at http://esa.un.org/unpp. Accessed 13 March 2008.

UNECE Timber Committee 2006. *Statement on Forest Products, Markets in 2006 and Prospects for 2007* (Report ECE/TIM/06/N01, UNECE Timber Committee, Geneva, 2006).

Wan, X., Xu, J.D., Liu, J.X., Xu, C.D., Yuan, G.W., Yan, G.Q., Huang, D. and Yuan, T.J. 2006. *General report on collective landownership reform in four provinces in the collectively-owned forestry system reform*. State Forestry Administration (in Chinese).

Wang, G.Y., Innes, J.L., Lei, J. F., Dai, S.Y. and Wu, S.W. 2007. China's forestry reforms. *Science* 318, 1557–1558.

Wang, G.Y., Innes, J.L., Wu, S.W. and Dai, S.Y. 2008a. Towards a new paradigm: development and implication of China's forestry in the 21st Century. *International Forestry Review*, 10(4):619-631.

Wang, G.Y., Innes, J.L., Wu, S.W., Dai, S.Y. and Lei, J.F. 2008b. The need to cut China's illegal timber imports – Response. *Science* 319, 1184–1185.

Wang, G.Y., Miao, G.P., Innes, J., Zhang, L., Dai, S.Y. 2009.New Market Systems for Post-Reform Development of Collective Forest Tenures in China: Progress, Issues and Challenges. XIII World Forestry Congress. Buenos Aires, Argentina. Oct. 18-23. Submitted.

Wang, Q.X., Liu, Y. and Pan, X.C. 2008c. Atmosphere pollutants and mortality rate of respiratory diseases in Beijing. *Science of the Total Environment* 391, 143–148.

Wang, G.Y., Innes, J.L., Zhang, X.P. and Wang, J.X. 2008d. Public awareness and conception on Min River watershed management and development, Fujian, China. *Society and Natural Resources,* submitted.

Wang, X.F. 2007.The first BCF-funded CDM project launched in Guangxi (in Chinese). Xinhua News Agency. Available at: http://news.xinhuanet.com/local/2007-01/17/content_5618103.htm. Accessed on 12 March 2008.

World Bank 2007.World Bank and DFID to help improve access to water and sanitation in Western China. Available at: http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/EASTASIAPACIFICEXT/CHINAEXTN/0,,contentMDK:21388586~menuPK:50003484~pagePK:2865066~piPK:2865079~theSitePK:318950,00.html. Accessed on 12 March 2008.

Wu, Z.M. 2001. The importance for establishment of ecological forest in Longquan. *Journal of Zhejiang Forestry Science and Technology* 21(4), 55–58.

Yang, D.P. 2008. *The green book of environment: Crisis and turning of China's environment.* Social Sciences Academic Press: Beijing, 329pp.
Yienger, J.J., Galanter, M., Holloway, T.A., Phadnis, M.J., Guttikunda, S.K., Carmichael, G.R., Moxim, W.J. and Levy II, H. 2000. Episodic nature of air pollution transport from Asia to North America. *Journal of Geophysical Research* 105, 26,931–26,945.
Zhang, J. and Gan, J.B. 2007. Who will meet China's import demand for forest products? *World Development (Oxford)* 35(12), 2150–2160.
Zhang, T, Fei, B.H. and Jiang, Z.H. 2005. China's plantation program: will be able to supply the growing needs of both wood products and pulp and paper products. Proceedings of the Conference "China's Boom: Implications for Investment and Trade in Forest Products and Forestry" held in January 2006 in Vancouver BC Canada, Forest Products Society.
Zhang, Y. 2007. Study on China imported wood from the ten Southeast Asian countries (in Chinese). Available at: http://www2.gxu.edu.cn/yjsh/newsview2.asp?id=88. Accessed on 12 March 2008.
Zhou, D.G. and Mei, C.T. 2000. Development of agricultural straw material industry in the 21st century. *Journal of Nanjing Forestry University* 24(5), 1–4.
Zhou, S. 2006. *Forestry in China. Historical transitions and industry developments*. Singapore, Thomson Learning.
Zhu, C.L. 2007. *Chinese furniture trade: Market control & service.* Presentation to International Consumer Product Safety Conference, Beijing, May 21–22, 2007. http://www.icphso.org/2007pdf/China/21May_Household/Zhu%20Changling-EN.pdf
Zhu, J.G. 2003. Progress of applying IT to the Chinese furniture manufacturing industry. *China Wood Industry* 17(4), 3–5.

4 THE DEVELOPMENT OF CHINA'S FORESTRY IN THE 21ST CENTURY[5]

Since 2000, there have been rapid and extensive changes in forestry policy in China. Investments in the forestry sector since 2000 have exceeded the total investments in the period 1949–99. For its Six Key Forestry Programs (SKFPs) alone, China has invested 183.5 billion Yuan (RMB) (ca. U.S. $22 billion) in the last 6 years and will invest a further 539.8 billion RMB (ca.US$ 68 billion) in the next 4 years (Table 4–1). Here, we provide an update on the major forestry reforms introduced since 2000.

Table 4-1. Investment in the six Key Forestry Programs in the period of 2000–2005 Assessment. Units are in 10 thousand Yuan (RMB). (Adapted from State Forestry Administration, 2000–2006; State Forestry Administration, 1993–2006; and the Research Group of Sustainable Forestry Development, 2003).

	Total	NFPP*	CCFC	SCP	FIDBP	3Ns&YRB	WCNRDP
Starting year		1998–2010	1999–2010	2001–2010	2001–2010	2001–2010	2001–2010
Planning	73770000	9680000	35500000	3690000	720000	6740000	6920000
2005	3616302	620148	2404111	332625	15410	192556	51452
2004	3510242	681985	2142905	267666	20560	352661	44465
2003	3339160	679020	2085573	258781	31297	232083	52406
2002	2558000	933712	1106096	123238	38986	316711	39261
2001	1664390	949319	321425	44988	24675	303066	20917
2000	762489	608414	154075				
1999	510199	409225	100974				
1998	227761	227761					
Total	16188543	5109584	8315159	1027298	130928	1397077	208501
% of completion	21.9%	52.8%	23.4%	27.8%	18.2%	20.7%	3.01%

* The abbreviations used in the title row are explained in Table 4–2.

Massive investment in the SKFPs, strong demand for wood, and increasing pressure from environmental groups has led to calls for reform of forest ownership. Forests are considered the last battleground for much-needed land-tenure reforms in China, where old laws and practices still present a major barrier to the development of China's forest estate. In 2004, several provinces in the south began to reform forest ownership policies, introducing cuts in forest taxes, free-market mechanisms for forest asset transfers, and private support systems for forestry. These reforms are intended to improve forest infrastructure, enhance the competitive power of Chinese wood products, and improve environmental quality.

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China is facing many problems that affect social harmony, including growing pressure on the environment and natural resources. Past government policies have favored economic growth over the environment, but the Central Government has now proposed a science-based approach to development designed to realize balanced sustainable development (Ma, 2006). However, in practice, local governments continue to put economic growth ahead of any concern for the environment, which has led some critics to call for stronger Central Government control.

China's rapid economic growth, increased capital investment, and growing middle-class consumption have driven up the demand (and prices) for wood products. China not only needs wood to meet domestic demand, it also has a growing and very successful export industry. In 2006, the forest products trade in China was worth US$ 47.07 billion, a 23% increase over 2005. Forest product imports were valued at $19.39 billion (a 10% increase over 2005) and exports at $27.68 billion (a 34% increase). The trade in the first 6 months of 2007 was valued at $27.2 billion, a 35% increase over the same period in 2006 (Cao, 2007). By 2006, China had emerged as the world's largest exporter of furniture, accounting for 43% of U.S. and 33% of European wood furniture imports (UNECE Timber Committee, 2006). To meet the growing international demand for sustainability assurances in the production of forest products, China has developed a national certification standard and is seeking endorsement of its standard by the international Program for the Endorsement of Forest Certification (PEFC).

4.1 THE SIX KEY FORESTRY PROGRAMS

The SKFPs cover more than 97% of China's counties and target 76 million hectares of land for afforestation. The Natural Forest Protection Program (NFPP) was introduced in 1998 after a logging ban prompted by the most devastating floods in Chinese history (Zhang 2000). After a series of pilot studies, five additional programs were established to promote a more sustainable forest policy (Table 4–2).

4.1.1 Advances and successes

During the past 8 years, the NFPP has brought 98 million ha. of forest under effective protection. Logging natural forest has been banned in the upper reach of the Yangtze River and in the middle and upper reaches of the Yellow River. Timber production in the Northeast and Inner Mongolia has been successfully reduced from 18.24 million m^3 in 1997 to 10.99 million m^3 in 2006 (State Forestry Administration, 2005, 2006 and 2007), and 0.67 million displaced forestry workers have been resettled (State Forestry Administration, 2006).

Table 4-2. The six Key Programs in forestry. (Adapted from State Forestry Administration, 2000–2006; Research Group of Sustainable Forestry Development, 2003).

Program	Details
Natural Forest Protection Program (NFPP)	Aim: to rehabilitate and develop natural forests. The program involves 734 counties and 167 forest industry bureaus in the upper reaches of the Yangtze River, the upper and middle reaches of the Yellow River, northeast China and Inner Mongolia. The three most important objectives for the period 1998–2010 are the protection of existing natural forest resources, the acceleration of the fostering of forest resources, and the relocation of 741,000 redundant forest workers.
The Conversion of Cropland to Forest Program (CCFP)	Aim: to reduce soil erosion in critical areas. It plans to return 14.7 million hectares of farmland to forests and afforest 17.3 million hectares of barren hills and wasteland suited to afforestation between 1999 and 2010. By completion, the area covered by forest and grass in the program area will rise by 5 percent, soil erosion on 86.7 million hectares of land will be stabilized, and 103 million hectares of windstorm-control and sand-stabilization areas will be established.
Sand Control Program for Areas in the Vicinity of Beijing & Tianjin (SCP) (third stage of the project)	Aim: to reduce the hazard of sandstorms in areas surrounding Beijing. It covers an area of 460,000 km^2. It is planned to return 2.63 million hectares of farmland to forests, afforest 4.94 million hectares of land, develop 10.63 million hectares of grassland, build 113,800 facilities to support water conservation, regulate 23,000 km of drainage areas and resettle 180,000 people for ecological improvement purposes between 2001 and 2010.
Three North Shelterbelt Development Program and the Shelterbelt Development Program along Yangtze River Basin (3Ns&YRB) (fourth stage of the project)	Aim: Rehabilitation of degraded and desertified land. It is planned to afforest 9.46 million hectares of land and rehabilitate 1.3 million hectares of desertified land between 2001 and 2010. By program completion, the forest cover in the area covered by the program will be increased by 1.84%, and 12.66 million hectares of desertified, salinized and degraded grasslands will be protected and rehabilitated. In the lower-middle reaches of the Yangtze River, it is planned to afforest 18 million hectares of land, improve 7.33 million hectares of low-efficiency shelterbelts and regulate and protect 37.33 million hectares of existing forests during the period in 2001–2010.

Table 4-2 (cont.). The six Key Programs in forestry. (Adapted from State Forestry Administration, 2000–2006; Research Group of Sustainable Forestry Development, 2003).

Wildlife Conservation and Nature Reserves Development Program (WCNRDP)	Aim: increased conservation of critical species. Priorities are being given to three projects between 2001 and 2010. The first involves completing 15 wild fauna and flora protection projects, including those for the giant panda, golden monkey, Tibetan antelope and a number of orchids. The second involves completing 200 nature reserve projects in forests, wetland ecosystems and areas affected by desertification, 32 wetland conservation and comprehensive utilization demonstration projects and 50,000 nature reserve districts. The third project involves completing the germplasm pools required for wild fauna and flora conservation, a national research system for wild fauna and flora and the establishment of appropriate monitoring networks. By 2010, there should be 1,800 nature reserves, including 220 State-level ones, covering 16% of China's total land area (i.e., double the figure suggested by (1)). The protection of these reserves is enforced, but some economic activities are permitted (such as the harvesting of bamboo).
Forest Industrial Base Development Program in Key Regions with a Focus on Fast-Growing and High-Yielding Timber Plantations (FIBDP) (third stage of the project)	Aim: to ease the shortage of timber supply and reduce the pressure of timber demands on forest resources. It plans to establish 13 million hectares of fast-growing, high-yield timber plantations in three phases between 2001 and 2015. At completion, this program will provide 130 million cubic meters of timber annually, meeting 40% of China's commercial timber consumption, and thus maintaining an initial balance between the supply of and demand for timber.

There has also been significant progress in afforestation, with 28 million ha. of plantations established in the past 6 years (State Forestry Administration, 2005–2007). The Conversion of Cropland to Forest Program (CCFP) – which pays farmers to plant trees rather than crops – has converted 8.8 million ha. of cropland into forests (State Forestry Administration, 2006). Under the CCFP, soil erosion has been reduced by 4.1 million ha, representing a 4.1% annual reduction. For the first time since the establishment of the People's Republic of China, desertification has been reversed, from an annual increase of 3436 km^2 at the end of the 20th century, to the current annual reduction of 1283 km^2 (State Forestry Administration, 2006). This has been largely achieved through the Sand Control Programs for areas in the vicinity of Beijing and Tianjin, the Three-North Shelterbelt Development Program and the Shelterbelt Development Program along the Yangtze River Basin programs. During 2001–2006, 831 natural reserves were created, and 19.5 million ha. of forestland and special sites were protected under the Wildlife Conservation and Nature Reserves Development Program (State Forestry Administration, 2005–2007).

The total area of plantations in China now amounts to 53 million ha, with forest cover increasing from 16.6 to 18.2%, and the forest stock volume increasing from 11.567 billion m^3 to 12.456 billion m^3 since the start of the SKFPs (State Forestry Administration, 2005).

4.1.2 Problems and obstacles

The booming economy has placed greater pressure on a system not yet capable of balancing the growth in wood demand with environmental needs and social justice. Although the Central Government has been proactive in trying to improve China's forestry basis, the on-the-ground effects at the state and local levels have been mixed. For example, the Central Government has been providing major funding for tree-planting, but local governments lack the funding to implement the programs effectively (State Forestry Administration, 2003).

Transfer of responsibilities to local governments means that there is no guarantee of continued funding for the stewardship of the new forests. It is also unclear whether resettled workers and local farmers are directly benefiting from some of the projects. In areas covered by the logging ban, the decline of community services may have exacerbated their economic difficulties. Local corruption is widespread and under-regulated corporations have been accused of usurping user rights and failing to compensate farmers for their land.

Figure 4-1. Forest police patrol in a protected forest area. China has about 60,000 specially trained forest police to enforce policies such as the logging ban. Photo credit: Forest Police Bureau, State Forestry Administration.

Reforming China's complex system of forest ownership and user rights is critical to the long-term implementation of its forestry programs. Land ownership reforms will provide farmers with rights to plant trees for income and will give incentives to protect forests. The reforms involve transfer of land to individuals or companies, and compensation packages for those not receiving land. In the CCFP program, the delay in ownership reform has resulted in farmers planting their forest land even though they have no property rights. In some areas impacted by the NFFP program, the needs of local people have been inadequately considered and compensation levels have been too low to offset their losses. Progress in the Forest Industrial Base Development Program, which focuses on fast-growing and high-yielding commercial timber plantations, has been slow, with uncertainty over forestland ownership, resulting in only 0.19 million ha. of new plantations established in the last 6 years (State Forestry Administration, 2005–2007).

4.2 OWNERSHIP REFORMS AND AUXILIARY POLICIES

Forest ownership reform started in Fujian and Jiangxi provinces and has been extended to the provinces of Zhejiang, Liaoning, Heibei, Shandong, Anhui, and Guangdong. The Central Government has removed or reduced forestry taxes to encourage tree planting and forest products manufacturing. Local governments have removed provincial taxes and some fees on forest products. For example, Fujian province has reduced forest product taxes and fees from 46% of the total sale price to 26%. Simultaneously, the government is using transfer payments to support local governance organizations that used to be financed by forest taxes and fees. The Jiangxi provincial government lost $182.5 million in tax revenue but had this sum supplied instead by transfer payments. As a direct result of this change, the average annual cash income for each farmer increased by 13%, or just over $10 (SJDITF, 2007).

To provide a mechanism for the trading of forest assets – land and timber – China established its first pilot futures market, the Fujian Yong'an Forestry Elements Market, in 2004. The market consists of a forest and forestland registration centre, a forest resource evaluation centre, a timber and bamboo exchange, a legal and technical service centre, and a labour training centre. By May 2007, the market had bought and sold 20,766 ha. of forest and provided purchasing loans worth $63.8 million (Sun, 2007). In Jiangxi province, there are now 36 such markets established or being set up, and the number of deals has exceeded 3000, valued at $120 million (SJDITF, 2007).

4.3 FUTURE FOREST MANAGEMENT STRUCTURES

The Chinese government is beginning a new phase of forestry reforms intended to open the forest sector to much greater individual and corporate participation, largely through private sector financing. This represents a major break from the past, when most forestry activities were managed through the government. It aims to increase China's forest cover to 26% by 2050, to improve environmental quality, and to develop a competitive forest industry that depends largely on a domestic fibre supply.

To achieve these goals, several changes in policy are being instituted (Central Committee, 2003), beginning with the separation of ecological and commercial forests, each having separate management policies. However, the policies for managing ecological forests and commercial forests are not yet fully in place and need to be integrated with sustainable forest management systems.

The government will strictly protect ecological forests, increasing fire, pest, and biodiversity protection and preventing logging or the conversion of ecological forests to other uses. Local communities and farmers will be compensated if their land is classified as ecological forest. On commercial forests, the government will grant much greater leeway to develop management plans and will allow farmers the freedom to determine harvest age (based on economic maturity), apply intensive forest management, select tree species, pursue economic benefits, and harvest on their own timetable based on agreed forest management plans. The government will also allow regional planners to use private funding to achieve these goals. The government will no longer control, but rather, encourage, the development of the commercial wood products trade.

Although the reforms represent a major shift in policy, the government will continue to be the ultimate authority in regional planning, zoning, and policy direction. The government will still govern forest asset ownership and transference rights, such as issuing licenses for land-use rights, forest ownership, and ownership exchange. It will set regulations to require forest practices to follow sustainable forest management and will encourage the private or public sector to fill gaps to provide services for forest management, such as management consultation, road-building, nurseries, wood markets, and logging.

4.4 REFERENCES

Cao, Q.Y. 2007. State Forestry Administration Press Conference (in Chinese), www.forestry.gov.cn/xwfbh/xwfbh070912.asp.

Central Committee of the Communist Party of China and China State Council. 2003. *Directive to enhance forestry development*. Issued 25 June 2003; Xinhua News Agency, Beijing. Accessed at 11 September 2003. http://news.xinhuanet.com/zhengfu/2003-09/11/content_1075042.htm

Ma, J. 2006. A path to environmental harmony. *Chinadialogue.* Accessed at 30 November 2006); www.chinadialogue.net.

State Forestry Administration. 2003. *A report for monitoring and assessment of the social-economic impacts of China's Key Forestry Programs*. China Forestry Publishing House: Beijing.

State Forestry Administration. 2000–2006. *China forestry development report*. China Forestry Publishing House: Beijing.

State Forestry Administration. 1993–2006. *China forestry statistical yearbook.* China Forestry Publishing House: Beijing,

Research Group of Sustainable Forestry Development. 2003. *Study on China sustainable forestry strategic development.* China Forestry Publishing House: Beijing, China (In Chinese).

SFA (State Forestry Administration). 2006. *Enhancing forestry ecological improvement and accelerating development of the industry*. State Forestry Administration, Beijing.

SJDITF (Six Joint-Departmental Investigation Task Force). 2007. *Investigation report on Jiangxi forest ownership reform*. State Forestry Administration. Beijing, China.

Sun X.X. 2007. Fujian forest-ownership reform on-the-spot report. *Chinanews.* Accessed at 6 July. 2007. www.chinanews.com.cn/cj/kong/news/2007/07-06/973437.shtml. p. 15 (in Chinese).

UNECE Timber Committee. 2006. *Statement on forest products markets in 2006 and prospects for 2007*. Report ECE/TIM/06/N01, UNECE Timber Committee, Geneva.

Zhang, P.C., Shao, G.F., Zhao, G., Le Master, D.C., Parker, G.R., Dunning, J.B. Jr. and Li, Q.L. 2000. China's forest policy for the 21st century. *Science* 288 (5474): 2135–2136.

5 ACHIEVING SUSTAINABLE RURAL DEVELOPMENT IN SOUTHERN CHINA: THE CONTRIBUTION OF BAMBOO FORESTRY[6]

5.1 INTRODUCTION

There are approximately 87 genera and 1,500 species of bamboo in the world, with roughly 100 species being of economic importance (Ohrnberger, 1999). Globally, there are approximately 14 million ha. of bamboo forests, distributed mainly in Asia, the Pacific, the Americas and Africa. A significant proportion of these forests are located in China, where there are more than 500 species spread across in 35 genera (Li and Kobayashi, 2004). Of these, 56 species have been recommended for the production of edible shoots, 58 species for timber production and 18 for pulp and paper production (Li and Kobayashi, 2004). Bamboo has a 7000-year history of cultivation and utilization in China and, today, bamboo is still used to make many household articles. Bamboo shoots are a major food source. The physical and mechanical properties of bamboo timber make bamboo an ideal material for houses, scaffolding, supporting pillars, and work sheds.

The introduction of sustainable development to China has created new directions for bamboo management (Zheng and Hong, 1998). It has been become one of the main foci for sustainable forest management, environmental protection and rural development (Li, 2001; Hui *et al*., 2003; Chen, 2003). The unique characteristics of bamboo forests make them important for sustainable forest management in southern China for a number of reasons (Ruiz Perez *et al*., 2001, 2003). Bamboo forest can be regenerated easily using stem cuttings, and reaches maturity at around 5–6 years (Zheng, 1998). Bamboo forests develop by spreading rhizomes; this well-developed underground system promotes soil stability, water conservation and wildlife. The forests need to be thinned every year in order to keep the forest ecosystem healthy (Scurlock, 2000). This provides a constant income from the timber for farmers without damaging the environment. Bamboo timber is a good substitute for wood, as current technology enables the processing of bamboo strips into bamboo flooring, panels, boards, and laminated beams. Bamboo shoots, rich in fibre, are an important household vegetable and are also a traditional export product.

5.2 THE DEVELOPMENT OF BAMBOO IN CHINA

5.2.1 Development of bamboo forests and the bamboo industry

Driven by the requirements for sustainable forest development, there have been several major advances in bamboo management since 1977. The 2007 Forestry Statistical Yearbook reveals that there are 7.2 million hectares of bamboo forests (SFA, 2008), a 3.5 million ha. increase

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since 1978. In recent years, the area of bamboo has forest increased by 90,000 ha. annually, with much of it being Moso bamboo *(Phyllostachys heterocycla* var. *pubescens*) (Figure 5–1). The non-Moso forest area has also gradually increased in significance over time, and an increase in the economic value of non-Moso forests has encouraged farmers to convert agricultural land to bamboo forests.

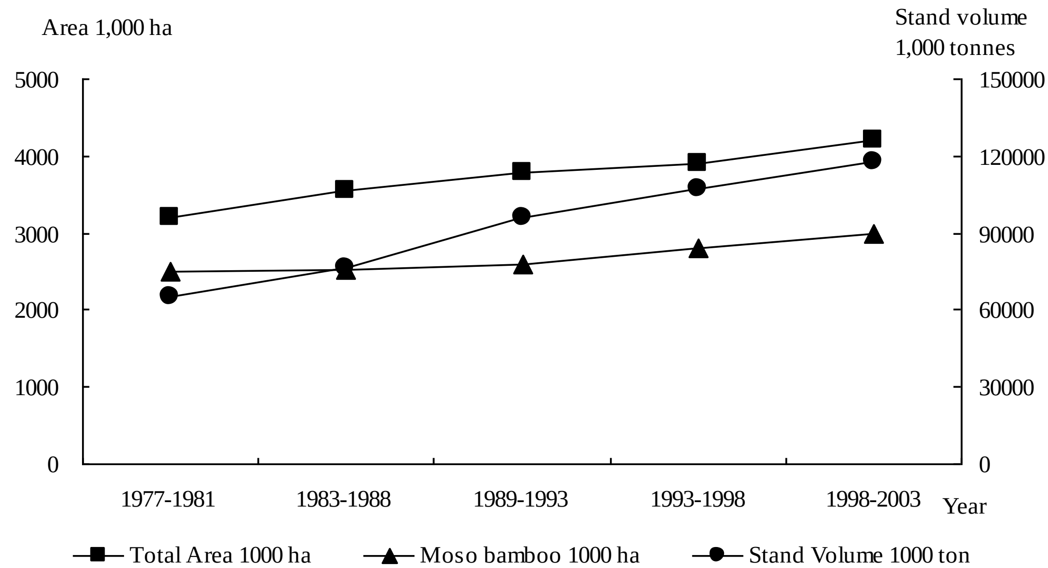


Figure 5-1. Development of bamboo forest in China since 1977. (Data derived from China National Inventory and State Forestry Administration, 1997–1998, 1993–1988, 1989–2003, 1993–1998 and 1998–2003).

Traditionally, 90% of the Chinese bamboo forest comprised Moso bamboo, concentrated in Fujian, Jiangxi, Zhejiang, Hunan, Guangdong and Sichuan Provinces (Zheng and Hong, 1998; SFA, 2008). Today, more than 20 species are cultivated in over 18 provinces, and bamboos occupy more than 3% of the total forest area, accounting for 25% of the value of China's forest exports (Ruiz Peréz *et al*., 2003). Today, Moso bamboo comprises about 3.5 million ha., accounting for about 63% of the total bamboo forest area in China. Fujian, Jiangxi, Zhejiang, and Hunan Provinces contain over 50% of the national bamboo forest estate (Table 5–1).

Table 5-1. Distribution of forest and bamboo in China. Source: Data derived from the Fifth National Continuous Forest Inventory Database 2005.

Province	Total forest area (1000 ha.)	Total area of bamboo (1000 ha.)	Percentage of bamboo
Fujian	12,150	681	5.6
Jiangxi	16,672	552	3.3
Zhejiang	10,180	510	5.0
Hunan	21,184	506	2.4
Guangdong	17,790	355	2.0
Sichuan	56,608	346	0.6
Guangxi	23,760	240	1.0
Anhui	13,817	203	1.5
Yunnan	38,264	125	0.3
Hubei	18,586	121	0.7

5.2.2 Increase in the quality and quantity of bamboo forest

Over the last twenty years, 60% of the low-value and low-productivity bamboo stands have been converted into high-quality and high-productivity stands. The average stand density has increased from 1350 to 2100 stems per ha, while the average diameter of Moso bamboo has increased by 33%. The amount of forest being managed intensively has increased from 6% to 15% (Li and Kobayashi, 2004). Although annual production has varied since 1978, a gradual increase in production is evident (Figure 5–2).

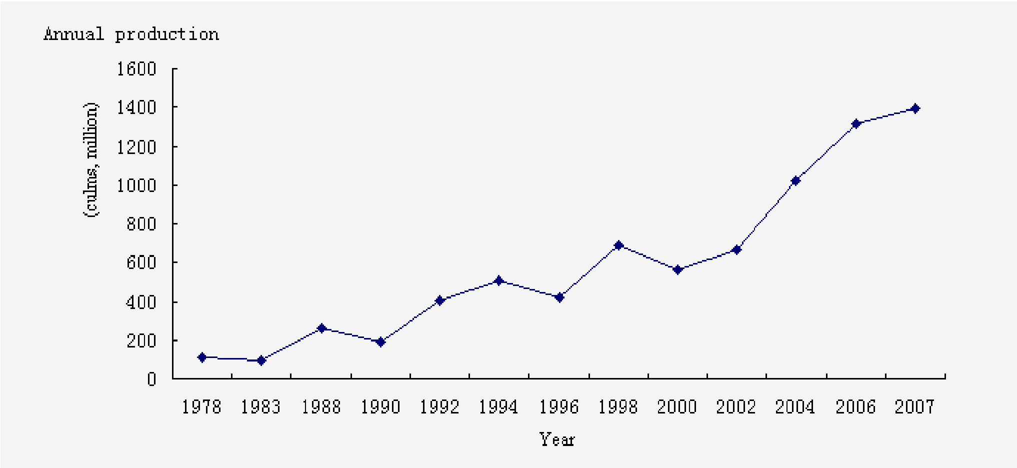


Figure 5-2. Annual bamboo production in China. Source: Data adapted from the China Forestry Statistical Yearbook (State Forestry Administration, 2007).

In 2007, the annual harvest of bamboo in China was approximately 1398 million culms, equivalent to 20 million m^3 of round wood. Bamboo manufacturing plants have increased from fewer than 2000 in 1977, to 12,190 in 2003. In 2003, over two million people were employed in the industry and more than ten million farmers were engaged in bamboo forest management (Chen, 2003).

5.2.3 Expanding utilization of bamboo

The development of bamboo processing technologies has enabled the use of bamboo in engineered flooring materials, plywood, laminated beams, boards and panels, all of which have greatly increased the utilization of bamboo products (e.g., Chen, 2003; Dong, 2003; Pande, 2008). In 2008, the production of bamboo flooring was about 20.5 million m^2, and bamboo plywood and panels exceeded 3.29 million m^3 (SFA, 2008), while in 2003 the figures were only 10 million m^2 and about 1 million m^3, respectively. The main application of bamboo plywood and panels is for the baseboards of containers, forming boards for concrete and cement, and for furniture and interior decoration. Bamboo can be used for pulp and paper. A large-scale bamboo paper and pulp mill was established in 1995 in Shaowu City (Fujian province). It alone has an annual production of 200,000 tonnes. Its annual bamboo consumption is 800,000 tonnes of green bamboo timber. The planned capacity of bamboo pulp production by the end of 2010 will reach up 3.95 million tonnes according to the China Eleven-fifth (2005-2010) National Plan (China National Development and Reform Committee, 2004; Chen, 2008).

5.2.4 Expansion of bamboo shoot production

The expansion of the bamboo shoot industry has been documented by Zhu (2003) for Lin'an County, Zhejiang Province. Here, there was a ten-fold increase in the area used for growing bamboo shoots between 1982 and 2002. Annual production of fresh shoots increased over the same period from 7280 tonnes to 135,250 tonnes, and its value increased from US$ 260,000 to US$ 39.4 million. While the changes coincide with a number of local government reforms (Kant and Chiu, 2002), similar increases have been seen elsewhere.

5.3 METHODOLOGY

We examined the role that bamboo forests has been playing in sustainable rural development in southern China, especially in Fujian and Zhejiang provinces. We focused on the issues surrounding bamboo development and the actions that are needed to facilitate a better contribution of the bamboo forest industry to local social, economic and ecological development.

The statistical data were derived through existing reports, publications and papers, and were supplemented by data from interviews undertaken in 2002 and 2003 in the target areas, and field survey data (including soil physical and chemical data) from the authors' current study areas in 5-ha bamboo (*Dendrocalamopsis oldhamis*) forest permanent research plots at Longtan Creek and ZhuYuan, Fuzhou National Forest Park, and from five of the main bamboo-producing counties in Fujian Province: Shaxiang, Jianou, Shaowu, Yongan and Jiangyang. The plots were established to test the relationship between bamboo forest management and soil productivity.

Interviews were conducted in the bamboo-growing areas of Fujian and Zhejiang provinces (Table 5–2) with farmers, bamboo resource professionals, managers from bamboo processing plants and trade centres, and local government officers in four towns with major bamboo industries.

Table 5-2. Type of interviewees in each of the four counties.

County	Farmer	Technical professional	Manager	Officer
Jian Ou, Fujian	122	16	16	26
Yong-An, Fujian	134	16	17	27
An Ji, Zhejiang	125	17	16	27
Lian An, Zhejiang	124	16	17	26

The interviews focused on current bamboo management strategies and related issues and specifically aimed to determine: the use of bamboo forest management models and their development, householder and community income structure derived from bamboo, the main bamboo product flows and the beneficiaries of these flows, bamboo management costs, taxes, and profits, the existence of participatory and decision-making processes, and any other issues and potential for the development of the industry. The interviews were based on an open-ended questionnaire that was dependent on the setting of the meeting and the situation of bamboo development in the area being considered. The questionnaire and interviews were conducted and analyzed in Chinese. A summary of the main aspects covered by the interviews is provided in Table 5–3. Data were analyzed using SPSS12 software package.

Table 5-3. Summary of the interview questions.

Aspects	Question
Personal information	• Bamboo owners/technical professionals/managers/government officers • Attitude toward bamboo management
Bamboo management model	• Model use in bamboo management chain– bamboo forest management, harvesting, processing, marketing and sale. • Integration and secure approaches in the model – products flow/money flow/information flows • Pros and cons of the models
Income structure (household and community)	• Total income/segments • % from bamboo forest management • % from bamboo raw products and processed products • % from market sale
Management cost, tax, profit	• Annual bamboo management cost/ per unit • Structure of costs – labour, materials • Bamboo production per unit area/harvest cost • Raw bamboo timber sale price • Profit from timber process • Taxes and fees associated with bamboo forest management and product sale
Governance, organization and association	• Ownership, organization and self-governance • Main training and education sources/process • Technical, management and marketing support from government, association, community and neighbours • Learning curve in bamboo management/development • Understanding of and attitude towards participatory management; change from participatory management • PRA decision-making processes
Issues from bamboo management	• Issues related to management and incentive policies • Financial issues • Land use and ecological problems • Obstacles associated with the management model
Suggestions	• Good management practices • Improvement of government, association, and community to support • Future planning

Secondary statistical data were derived from the national and provincial forest inventories (Chinese Academy of Forestry Planning and Design, 2005), statistical yearbooks (Chinese Forestry Administration, 2004) and general industry surveys from the last 25 years (1977–2003) (published in the appropriate regional statistical yearbooks). The data were gathered to identify the development of bamboo resources and the bamboo industry, with particular attention being paid to the roles played by the bamboo industry in social development, economic growth and ecosystem protection in China.

5.4 RESULTS AND DISCUSSION

5.4.1 Sustainable forest management and rural development

Over the past 20 years, the ability to process bamboo and its ecological importance has transformed bamboo into an important economic product relevant to rural development and an integral part of ecosystem protection schemes (Ruiz Peréz *et al.*, 1999). As a result, traditional methods of management of the resource have shifted to its incorporation in sustainable forest management and rural development.

Economic development associated with sustainable bamboo management

Typical examples can be found in any of the ten "China Bamboo Hometowns"[7]. These counties are rich in bamboo resources and are also located in remote and relatively poor areas. Their economies are now dominated by the manufacturing of bamboo products, and markets for cultural and aesthetic interests have been developed. The bamboo forest industry directly or indirectly contributes more than 20% to their GDP. In Anji County, Zhejiang Province, where bamboo forested land accounts for 34% of the total area, the industry generated US$ 0.5 billion in 2001, about 28% of the total county's GDP. On average, each household in the area obtained US$ 762 from bamboo management, a fourfold increase since 1987. The income from bamboo accounted for 38% of total household incomes. In Jianou County, Fujian Province, the bamboo industry generated US$ 300 million revenue in 2004, with 63% coming from bamboo timber and shoot processing. Income from the export of bamboo products was about US$ 12 million. The per capita income of farmers generated by bamboo has increased 38% since 1998, and is now 48% of their total annual income. The relationship between the development of the forest and the increase in income from bamboo management is shown in Figure 5–3.

[7] The China State Forestry Administration designated ten counties as the "China Bamboo Hometowns" in 1996. They are: Jianou and Shunchang, Fujian Province; Linan and Anji, Zhejiang Province; Congyi and Jiangxi, Yifeng Province; Guanning, Guandong Province; Guande, Anhui Province; Taojiang, Hunan Province; Shishui, Guizhou Province.

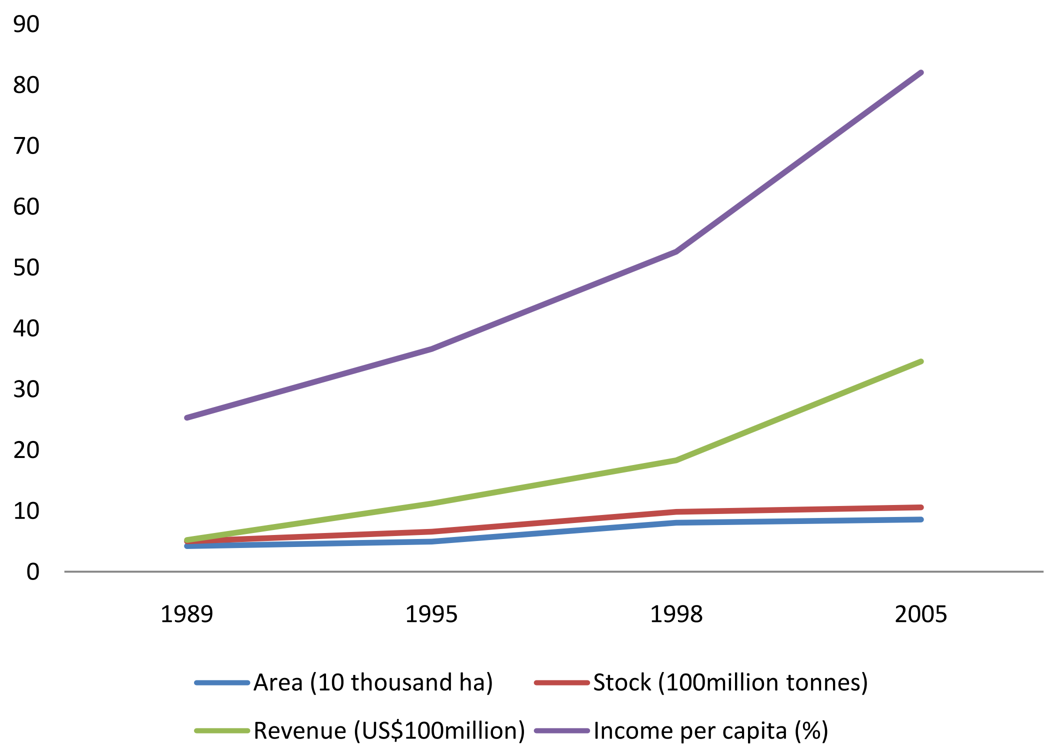


Figure 5-3. Development of bamboo management indices since 1989 in Jianou City. (Data provided by the Jianou Forestry Bureau).

We examined the contributions made by bamboo and related industries to household earnings and the local economic sector in Huangdao, Jianou City, in 2002. Bamboo accounted for 28% of annual household income, slightly lower than agriculture and forestry. 71% of the income from bamboo was generated from the sale of bamboo timber, with bamboo shoots and top 'logs' accounting for the remaining 29%. At the township level, about 25% of the total revenue was generated by the bamboo forest industry.

The development of a large bamboo-processing industry has had significant impacts on local managers. The scattered, small-scale, and family-based bamboo management models were unsuitable for industrial development due to lack of cost-effectiveness. Instead, as recommended by Zheng and Lu (2003), there has been a gradual increase in the number of management models that combine farmers, professional associations, bamboo exchange markets and bamboo manufacturers together into bamboo industrial partnerships. The basis for these organizations is the mutual sharing of risks and benefits.

The analysis of the data reveals that four bamboo management models can be described. These are summarized in Table 5–4. In the first stage, farmers work together to share experiences and knowledge and to consolidate their sales. Then, jointly with bamboo trade centres and manufacturers, a more professional and robust model is created. Currently, the four concurrent management models reflect differences in local economic well-being. However, the most successful model for bamboo development appears to be the "company + bamboo production bases + household" model. In this, companies, manufacturers and traders are the consumers of bamboo timber and shoots. As a result, farmers experience a more secure market demand, allowing them to organize themselves for large-scale production and to develop long-term management objectives (e.g., Li *et al*., 2004).

Table 5-4. Management models for the development of a sustainable bamboo industry.

Model	Functions
Households – Professional association	Farmers' self-organized association provides professional training, unifies pricing and marketing.
Households – Exchange markets	Contracted or market-oriented production. Some exchange markets or centres provide a portion of payment to support farmers and secure their supply.
Households – Manufacturers	Demand-oriented production. Manufacturer secures the farmers' production, and some manufacturers provide farmers with financial support and simple machinery to process raw materials into semi-manufactured products.
Household – Bamboo production bases – Companies	Multiple chains and complex systems.

Several international organizations have become involved in bamboo development in China and have been very successful, especially the International Network for Bamboo and Rattan (INBAR), the World Bank and the Deutsche Gesellschaft für Technische Zusammenarbeit GmbH (GTZ), all of which have helped to establish management models for bamboo development. In 2003–2004, financial institutions, such as the China Insurance Company, the Agricultural Bank of China and the Industrial and Commercial Bank of China, were directly or indirectly investing in the bamboo forest industry. Although the results are not readily apparent, the industrialized models are likely to result in more sustainable management due to the diversity of investing partners.

Societal development associated with sustainable bamboo management

Ruiz Peréz *et al*. (2004) have shown the economic contribution of bamboo management to farmers, and how different income levels gained from bamboo have varied and have been dependent on the stage of rural development. However, this study only dealt with the direct income from bamboo. We have adopted a more holistic approach that considers the combined effects of the entire bamboo forest industry on society. We examined the development of bamboo since 1985 and classified it into four stages (Table 5–5), moving from small-scale production for timber and shoots to large-scale industrial production.

Table 5-5. Bamboo development stages in China.

Stage	Goal	Measurement
First stage (1983–1990)	Improvement of bamboo forest quality and quantity	Bamboo forest rehabilitation, expansion and fertilization. Production is family-oriented, with hand-made products.
Second stage (1990–1997)	Development of bamboo manufacturing	Industrialized use of bamboo timber and shoots. Large facilities and employment.
Third stage (1997–2005)	Development of a bamboo market system and trade network	Centralized and mass bamboo trading center and exchange market.
Fourth stage (2005–2015)	Sustainable bamboo forest management and industry development	Adoption of a sustainable management approach and ISO 1400 criteria and indicators.

The development of bamboo management systems has brought prosperity to local economies. For example in Taojiang County, Hunan Province, more than 20% of the population is now working in bamboo-related businesses; among them, 100,000 people are engaged in bamboo forest management, 30,000 are employed in the bamboo industry, and around 10,000 with bamboo products trading. In Anji County, Zhejiang Province, there were only eight private bamboo manufacturers with about 1,000 employees in 1992. By 1998, this had increased to 573 bamboo manufacturers and 17,180 workers, with 50% of them being women. By 2003, the number had increased to 1600 bamboo manufacturers and more than 20,000 workers. The importance of women in bamboo-related industries is something that has previously been reported (e.g., Huang and Yang, 2004), although primarily during the first two stages of development.

One of the most significant recent social developments has been the adoption of participatory forestry and participatory rural appraisal (PRA) (Chambers, 1994a, 1994b, 1994c; Kapoo, 2001; Fagerstrom, 2003a, 2003b; Fraser *et al*., 2006) processes for the development of new models of bamboo management. These processes try to help local people shift from commune (government) management-oriented systems to proprietor (household ownership) oriented management systems. In several counties in Fujian and Zhejiang Provinces, even though the farmland ownership reforms were implemented in the 1980s, people continue to manage bamboo forests in a highly prescriptive fashion. Particularly in remote areas, local government officials are still using planned economy systems to allot a task to each farmer and still decide which species farmers should plant, where the planting should take place, how the bamboo forest should be managed and how benefits should be allocated. Due to the lack of farmer participation, government technical support, financial motivation and market orientation, bamboo management in such areas was trapped in a simple reproduction cycle. On revisiting these areas in 2002 and 2003, after participatory forestry approaches had been adopted and put into practice, many significant changes were observed, signalling greater motivation amongst farmers for community involvement. The shifts from traditional management to participatory management are summarized in Table 5–6.

Table 5-6. Changing patterns of bamboo management before and after implementing the participatory management (1998–2003).

	Traditional management (1998)	Participatory management (2002 and 2003)
Main body	Government	Household (farmer)
Decision making process	Government leading systems 'top-down' Decision maker: government	Participatory systems 'bottom-up' Decision maker: stakeholders
Beneficiaries	Government state-owned firms, farmers	Households, shareholders
Management purpose	Timber and shoots	Multiple purposes
Ownership	Public	Private
Motivation of the farmer	Passive	Active (self-motivated)
Marketing approach	Provide mainly to state-owned manufacturers or trade companies	Self-determined and market-oriented
Support systems	Local government and affiliated institutions (vertical) Limited support	Government, financial institutions, research and consulting firms, and local community (horizontal) Newly developed support systems provide a huge range of practical and technical support and training for farmers
Participants	Male dominated	Males and females participate equally in activities

Ecosystem development associated with sustainable bamboo management

The unique characteristics of bamboo make it an ideal species for barren-land afforestation and riparian protection (Scurlock, 2000; Ruiz Perez *et al.*, 2001; Ruiz Perez, 2004). Bamboo plantations in the Min, Jiulong and Shajiang River watersheds in Fujian province are good examples of the important role that bamboo plays in sustainable ecosystem development in these over-exploited, human-dominated areas.

The survey (Zheng and Wang, 2002) revealed that in the Shaijiang River watershed, a riparian bamboo forest (*Dendrocalamopsis oldhamii*) was planted after the major floods in 1998 and, since then, soil erosion has decreased by 30%. In a bamboo (*Phyllostachys sulphurea*) forest in the Min River Watershed, we found that canopy water interception was 128 mm in stands with a density of 833 stems per hectare (3m x 4m), higher than local Masson pine (*Pinus massoniana*) forest of a similar density, which had 77 mm interception. The water-retaining capacity of bamboo forest is around 3700–4200 t ha^{-1} of water, 30–45% more than Chinese fir

(*Cunninghamia lanceolata*), and 1.5 times greater than Masson pine. The data reveal that the sympodial bamboos (e.g., *Dendrocalamopsis oldhamii* and *Dendrocalamus latiflorus*) that are widely planted on roadsides, riversides and house-sides within the flood plain not only increase soil protection and river bank stability, but also act as wind breaks and in the amelioration of visual quality. Consequently, it can be concluded that bamboo forests provide better riparian protection than some other forest types, stabilizing river banks and protecting them from erosion.

Recently, due to the rapidly expanding bamboo forest resources and manufacturing sector, there has been an increasing focus on sustainable bamboo planting and growing (Ruiz Perez *et al.*, 2004, Pande and Pandey, 2008), and on the configuration of bamboo forest ecosystems, such as use of a bamboo root cover technique to protect soil and promote bamboo shoot development. Attention is also starting to focus on mixed forest and landscape configurations – planting bamboo with Chinese fir, Masson pine, schima (*Schima superba*), and kao (*Castanopsis fargesii*)**.**

5.4.2 Major issues for sustainable bamboo development

Although provincial governments are paying significant attention to bamboo development, there are still many problems. Some of these issues are related to current systems of governance, which appear to require reform, while others are related to local economic development and traditional management practices.

Ecological issues

The interviews revealed that large-scale development of bamboo forests has helped reclaim barren land and enhance local ecosystems. At the same time, improper management practices have caused serious ecological problems. Firstly, the monoculture of bamboo forests has had disastrous consequences in some ecosystems. Forest inventory data from the ten main bamboo counties show that in many townships, bamboo monocultures cover areas in excess of 1000 ha. Secondly, traditional cultivation approaches and intensive management have resulted in soil pollution and erosion. Many farmers still use out-dated methods to cultivate bamboo forest, such as annual weeding, digging, and fertilizing, as well as harvesting bamboo shoots without replacing the soil and protecting it. These practices are often conducted in spring, the wet season in China. In two 5-ha bamboo (*Dendrocalamopsis oldhamis*) permanent plots at Longtan Creek and ZhuYuan, Fuzhou National Forest Park, we observed by comparing with two ck plots, over a ten-year period, an average of 15 cm reduction in soil depth in plots treated using traditional cultivation methods. Analysis of soil samples from the five existing experimental sites at Shaxiang, Jianou, Shaowu, Yongan and Jiangyang in Fujian Province revealed that the intensive management of monoculture bamboo forest is contributing to the depletion of soil nutrient levels (Zheng and Wang, 2002). Over-exploitation has degraded soil productivity, which has also caused large-scale bamboo forest flowering and dieback. Currently, widespread diseases (such as Ceratosphaeria phyllostachydis) can also be related to the adoption of bamboo monocultures.

Bamboo development policies

The taxes on bamboo are higher than for other forest or agricultural products. The results of surveys conducted from 1999 to 2002 are shown in Table 5–7. There are between 13 and 16 different government taxes on bamboo timber, accounting for 30–50% of the total sale price.

Some local governments have also imposed additional fees. The high taxes imposed on the number of culms (instead of the area cultivated) have resulted in low profit margins (less than 5% in most cases), and have seriously affected the motivation of local people to manage bamboo forest in a sustainable way. They have also resulted in illegal removals. The differing tax rates between counties and provinces have caused many logistical problems. The Fujian Provincial Government implemented an incentive bamboo tax regulation in 2002, which postponed or waived the imposition of some of the bamboo taxes, but this has not completely resolved the problem.

Table 5-7. Current taxes for bamboo timber.

	Number of separate taxes	Taxes per culm (US$)	Percentage of sale price
Yongan City, Fujian Province	13	0.50	30%
Shouwu City, Fujian Province	13	0.34–0.57	36%–47%
Nanping city, Fujian Province	16	0.52	50%
Nanjin County, Fujian Province	13	0.28	46%
Liuyan city, Hunan Province	14	0.21	52%

Logging regulations are also hindering the development of a bamboo forest resource. In some areas, bamboo yields are regarded as timber, and permission is required for logging bamboo. Zhejiang province promulgated in 2004 a new regulation “Moso Bamboo harvesting regulation” that aimed to promote the development of bamboo resources and to replace the annual allowable cut (AAC) by an annual harvest quota (AHQ). This regulation has the appearance of an improvement in procedures but actually represents no real change in the current legal process. The AAC was determined every five years, then allocated on an annual basis, with some adjustments based on market and management requirements (such as disease, wind or snow damage).

Limitations of the household-based responsibility model

In China, the 1978 land reforms gave a certain amount of arable land to farmers to manage for a specific number of years (commonly on a 30-year renewable basis), based on the number of persons resident in the household. This was known as the Household Responsibility System (HRS). Some provinces allotted bamboo forest land to households, about 0.66 ha. (10 Chinese mu) for a 3-person family (in theory, the income from 10 mu of bamboo forest can support a family’s living expenses). This policy caused the fragmentation of bamboo forest, but has been successful in increasing farmer’s involvement in bamboo development. However, the HRS has only allocated certain management rights to farmers, rather than ceding full property rights. The development of the bamboo processing industry requires a large harvesting base and this has caused conflicts between small-scale farmers and large-scale industry. The most common conflicts have been between small-scale household management and the need for mass supply; between household self-sufficiency management and large-scale timber management, and between traditional management practices and sustainable management approaches. These conflicts have resulted in calls for the modification of the HRS. Consequently, the development of practical policies for the exchange and trade of bamboo forests has become a major issue for governments.

Duplication of bamboo processing and manufacturing facilities
The increasing supply of bamboo and the lack of advanced technologies available for timber and shoot processing have resulted in a proliferation of low-technology manufacturing facilities. According to the China National Industry Survey, 13% of bamboo mills have annual revenues above US$ 120,000 in China (see Table 5–8), but only 212 mills were regarded as new product producers, with 153 mills producing bamboo panels and 59 mills producing bamboo flooring. Of all the so-called industrialized products, only bamboo flooring, bamboo plywood and canned bamboo shoots can be traded in international markets. The utilization rates for bamboo flooring and plywood are only 30% and 50%, respectively. The manufacturing process is still largely dependent on labour-intensive processes, particularly gluing, which could be automated. This has resulted in formaldehyde emission levels from finished products being higher than the E1 European standard. The formaldehyde problem has also resulted in increasing concerns over the health of workers and the stability of products.

Table 5-8. Classification of the bamboo processing industry. Revenues are in 10,000 RMB.

Annual Revenue	<100	100–500	500–1000	1000–5000	>5000	Total
Number of mills	10,579	1195	380	27	9	12,190
Percentage	87%	9.8%	3.1%	0.22%	0.07%	100%

Over-dependence on bamboo
Although rural economies have diversified to a much greater extent than previously, they still depend on the bamboo industry. As a result, any failure could bring disaster to local economies and people's livelihoods. There is thus a question over the sustainability of bamboo management and the development of other industries.

The participatory management approach needs to be improved
The result shows the key to successful bamboo development lies in participatory forestry and PRA processes, but these require improvement. Firstly, local government officers continue to treat decision making and strategic planning as a privileged process. Farmers, on the other hand, are unaware of the importance of participating in these processes. Secondly, the PRA process is misunderstood. During interviews, 56% of government staff and 78% of farmers interpreted PRA as public consultation or hearings. Thirdly, conflicts exist between technical advisers and farmers. Advisors complain that farmers are rigid and stereotyped in their thinking, while farmers consider the information from technical advisors of little value and incognizant of local conditions.

The results of surveys undertaken in four townships in Fujian province are illustrative. The surveys focused on the main sources that farmers used to obtain their bamboo management skills. Public education and training courses (provided by government) accounted for only 11% and 14% of skills development, respectively, whereas 64% of farmers learned their skills from relatives or neighbours (Table 5–9).

Table 5-9. Sources of training for farmers.

Sources	Public media (TV, newspapers)	Relatives and neighbours	Training courses	Others
Percentage	11%	64%	14%	11%

5.5 CONCLUSIONS AND RECOMMENDATIONS

The bamboo forest industry has played an important role in the sustainable development of rural areas in southern China, especially in relation to ecosystem restoration and poverty relief (Chen, 2003). The active participation of farmers has improved self-governance and decision-making. However, there are still many areas that need to be improved if sustainable management and community development in the bamboo-dominated areas is to be achieved. For optimum strategic development, the relationships between social, economic and ecological systems need to be well-balanced in order to achieve a sustainable bamboo forest industry. Four elements required to achieve sustainable bamboo forest management in China are the conversion of the government's functions and roles, establishment of farmers as the main body responsible for the management of bamboo forest, public participation, and NGO support and service systems.

The government is gradually withdrawing from the economic arena and is concentrating more on facilitation and guidance. Based on the current situation of wood shortages, environmental fragility and the need for rural poverty relief, the government needs to take a number of steps to help the development of a sustainable bamboo forest sector, including developing its management, the processing industry and an appropriate marketing network. The results of the survey indicate that government should clarify land ownership, resolving management rights and property rights; it should develop national and regional strategic plans and normalize social services; it should develop support and consultation systems and a bamboo products market, and it should standardize bamboo management and logging practices and legalize preferential taxes to promote sustainable development.

Current forest taxes are based on yield, which means that the higher the yield per unit area, the more tax is paid. Higher yields generally result from increased investment or improvement management, and the tax system therefore fails to reflect or encourage the use of technology, investment or improved management. The survey identified that an area-based management system would form a suitable basis for taxation, and would also enable a better harvest level determination.

Participatory forestry has been playing an important role in many bamboo development areas, although there is still much room for improvement. The concepts and procedures of meaningful public participation require careful explanation to the many potential participants (e.g. Jin, 2004, Shi et al. 2008). Broad-scale public consultation, involvement and constructive critiques are important for bamboo management. Public involvement in strategic planning, decision making, project implementation, process monitoring and evaluation are critical to the participation process. Public participation is not only suited to understanding public concerns and absorbing local wisdom, but also generates awareness and attention, facilitating the public involvement processes itself (Jin, 2004).

As the privatization of the bamboo forest industry and the gradual withdrawal of government from the general business sector proceeds, there has been a growing need for public support and service systems to fill the position of the government and regulate business behaviour (Shi et al., 2008). It would appear that two types of public support and service organizations are required: self-organized associations and a public service and consulting system. The self-organized associations should regulate the general practices for trade, develop strategic planning for the sector, provide training and consultation, and be responsible for product quality control and marketing. The non-governmental public support systems should provide services for the bamboo forest industry, such as research institutes, consulting firms, project contractors, and business trade companies.

Farmers, as bamboo managers and beneficiaries, need to increase their awareness of their roles as stakeholders and need to take responsibility for the development of bamboo, not only for personal or family interests, but also for regional economic development, ecosystem restoration and long-term community development. Biodiversity, and soil and water protection, also need to be taken into account during daily management practices. China is a participant in the Montreal Process, which has developed criteria and indicators for sustainable forest management. These need to be incorporated into the principles of bamboo forest management.

A conceptual model for the sustainable development of the bamboo sector during the current period of economic transition in China is given in Figure 5–4. A combination of government, farmer, local community and NGO support systems is essential for the sustainable management of bamboo forests and for economic development. The government needs to withdraw from directly managing bamboo but, simultaneously, needs to establish new forms of management and service systems, thereby increasing public participation and the confidence of farmers.

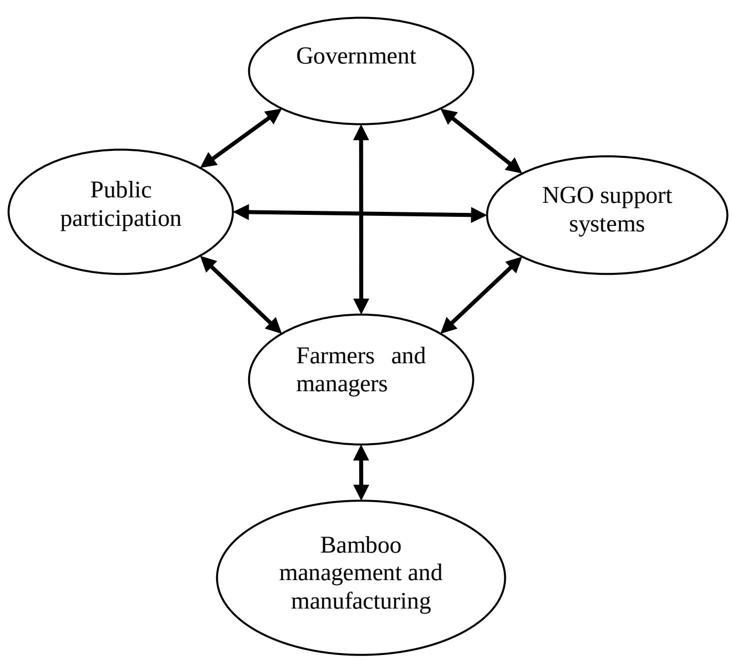


Figure 5-4. A conceptual model for bamboo management and development.

Bamboo forest is only one of many elements contributing to sustainable rural development in China; however, it encompasses all the potential advantages and disadvantages of Chinese rural reform. Privatization has limitations, and these limitations are becoming more apparent as the needs of economic development, namely reasonable scale resource management, cost effectiveness, and integrated business networks, are identified.

China has a ‘rural collective forest land privatization reform’ underway. This should help clarify ownership and responsibilities. However, land management rights and forest assets need to be exchangeable and tradable. This is important if farmers are to feel free to manage the forest, and such a change will encourage them to unite and form management groups or tree farms. The recognition of management rights and ownership will also enable the development of professional management teams that can manage the forest and coordinate with manufacturers to create a production chain. Such a trade mechanism is essential for improving bamboo management and Household Responsibility Systems.

A valid system for the zoning of bamboo forests is essential to achieving sustainable management, both for developed and developing counties with bamboo forests. As with many forests (Nitschke and Innes, 2005), bamboo forests would benefit from zoning, with the most appropriate classification being ecological forest, intensive management, and multiple purpose (Wang, 1989; Xiao, 2001; Lin, 2008). Furthermore, the intensive and multiple purpose management zones need to be divided into those used for the production of shoots, those used for timber production and dual-use zones. This would classify the function and purpose of all stands, thereby providing the security for managers to use the most appropriate management methods.

Mixed forests of bamboo and coniferous or broadleaved trees are unstable as they gradually become dominated by bamboo. The diversity of the understory is limited in most bamboo forests due to traditional practices such as weeding, logging, and the annual harvesting of shoots. To maintain biodiversity at the landscape level, large-scale monoculture bamboo forests need to be avoided. The configuration of broadleaf and conifer stands within the bamboo forest mosaic needs to be considered. Buffer zones need to be created to maintain biodiversity across the landscape; for example, mountain ridges should be planted with coniferous forests and riparian zones with either bamboo or replaced with local fire-resistant species. An increase in the number of bamboo species under management is also important for economic development and improvement.

Since the 1980s, the Chinese government has successfully established millions of hectares of bamboo forest, which have not only restored fragile ecosystems but have also benefited local communities by alleviating poverty and reducing timber shortages. However, since the privatization and industrialization of bamboo forests resources and timber manufacture, the demand for bamboo resources has been steadily increasing. This increase in demand has created several issues for sustainable development. A key to success will be to organize management systems and to identify the respective roles of government, farmers, public support systems and public participation in the bamboo management process. Sustainable forest management criteria and indicators along with auditing systems need to be incorporated into bamboo forest management and timber and shoot manufacturing. Key issues such as ownership, management classification, maintenance of biodiversity, and use of traditional practices remain unresolved and require further examination.

5.6 REFERENCES

China National Development and Reform Committee 2004. *The 2005–2010 National Plan for integration of forest and paper.* China National Development and Reform Committee, Beijing.

Chen, X.H. 2003. Promotion of bamboo for poverty alleviation and economic development. *Journal of Bamboo and Rattan* 2: 345–350.

Chen, Y. 2003. Status on bamboo products market & development trend in China. *World Bamboo and Rattan* 1 (4): 55–62.

Chinese Academy of Forestry 2005. The fifth national continuous forest inventory. Forest Resources Database (in Chinese) http://sdinfo.forestry.ac.cn/sjk_content.cfm?tt=05-M-015.xml&jj=jg2.July. 2005.

China Forestry Administration 2004. *2003 China forestry statistical yearbook*. China Forestry Publishing House, Beijing.

Dong, W.Y. 2003. The historical opportunity for sustainable bamboo industry development in China in the 21st century. *World Forestry Research* 16 (1): 26–30.

Fujian Provincial Bureau of Statistics 1993–2006. *Fujian statistical yearbook.* Fujian Provincial Bureau of Statistics, Fuzhou.

Hui, C.M., Yang, Y.M. and Yao, J.M. 2003. The ecological environmental benefits of bamboo and sustainable development of bamboo industry in China. *Journal of Southwest Forestry College* 23 (1): 25–29.

Huang, S.N. and Yang, L.Y. 2004. Gender issues in household bamboo industries: a case study of two villages in Xinping County, Yunnan Province of China. *Chinese Forestry Science and Technology* 3: 50–58.

Jin,A.W. 2004. *High Profit Management and Participatory Development of Phyllostachys Pubescens Plantation in Zhejiang and Fujian Mountainous Areas*. PhD dissertation. Zhejiang Forestry University.

Kant, S. and Chiu, M. 2002. Economic reforms, bamboo production and local economy: a case study of Linan County, Zhejiang Province, China. In: Kumar, A., Rao, I.V.R. and Sastry, C. (eds.), Bamboo for sustainable development. *Proceedings of the Vth International Bamboo Congress and the VIth International Bamboo Workshop, San José, Costa Rica, 2–6 November 1998*. pp. 155–171.

Li, M.H., Jin, L. and Zhang, X.F. 2004. Bamboo industry in Lishui: community participated sustainable development model of mountain area. *Journal of Zhejiang Forestry College* 21: 189–193.

Li, Z.H. and Kobayashi, M. 2004. Plantation future of bamboo in China. *Journal of Forestry Research* 15: 233–242.

Li, Z.Y. 2001.The bamboo industry: Realizing the green economics of sustainable development. *Ecological Economics* 4: 34–36.

Lin, H. 2008. Study on bamboo classification management. *Forestry Survey and Design* 1:136–139.

Nitschke, C.R. and Innes, J.L. 2005. The application of forest zoning as an alternative to multiple use forestry. In: Innes, J.L., Hickey, G.M. and Hoen, H.F. (eds.), *Forestry and environmental change: Socioeconomic and political dimensions*. CABI Publishing, Wallingford, 97–124pp.

Ohrnberger, D. 1999. *The bamboos of the world*. Elsevier, Amsterdam.

Pande, S.K. and Pandey, S. 2008. Bamboo for the 21st century. *International Forestry Review* 10(2): 134–146.

Ruiz Perez, M., Fu, M.Y., Yang, X.S. and Belcher B. 2001. Bamboo forestry in China: toward environmentally friendly expansion. *Journal of Forestry* 7: 14–20.
Ruiz Peréz. M., Belcher, B., Fu, M.Y. and Yang, X.S. 2003. Forestry, poverty, and rural development. Perspectives from the bamboo subsector. In: Hyde, W.F., Belcher, B. and Xu, J. (eds.), *China's forests. Global lessons from market reforms*. Resources for the Future, Washington DC,151–176pp.
Ruiz Peréz, M., Belcher, B., Fu, M.Y. and Yang, X.S. 2004. Looking through the bamboo curtain: an analysis of the changing role of forest and farm income in rural livelihoods in China. *International Forestry Review* 6: 306–316.
Ruiz Peréz, M., Zhong, M., Belcher, B., Xie, C. and Fu, M. 1999. The role of bamboo plantations in rural development: The case of Anji County, Zhejiang, China. *World Development* 27: 101–104.
Scurlock, J.M.O., Dayton D.C. and Hames, B. 2001. Bamboo: an overlooked biomass resource? *Biomass and Bioenergy* 19:229–244.
Shi D.J.,Yu, J.H.,Liu, Y.N.,Xie, Z.Z. 2008. The Construction of the Pattern of the Bamboo Farmers to Participate in Technological Innovation. Chinese Agricultural Science Bulletin 12: 158-162.
State Forestry Administration 2007. *China forestry statistical yearbook*. China Forestry Publishing House: Beijing.
State Forestry Administration 2004. *China forestry development report*. China Forestry Publishing House: Beijing.
State Forestry Administration 2008. *China forestry statistical yearbook*. China Forestry Publishing House: Beijing.
Xiao, J.H. 2001. Improving benefits of bamboo stands by classified management and oriental cultivation. *Journal of Bamboo Research* 20 (3): 1–7.
Wang, G.Y. 1989. A tentative study of classified management of state forest farms in Fujain province, China. *Journal of Fujian Forestry College* 9 (4):25–29.
Zheng, S.W. and Lu Z.M. 2003. Study on establishing a developed bamboo industry in Ningbo. *Journal of Zhejiang Forestry Science and Technology* 23: 67–72 (in Chinese).
Zheng, Y.S. and Hong, W.1998. Mao Bamboo Management. *Xiamen University Press*: Xiamen, 99pp.
Zheng, Y.S. and Wang, G.Y.2002. *Impact of Mao Bamboo on Ecological System and Nutrient Level in Fujian*. Fujian Department of Forestry; Fuzhou. p.210.
Zhu, Z.H. 2003. The industrialization and market orientation of bamboo shoot production in Lin'an County: a case study. *Journal of Bamboo and Rattan* 2: 441–452.

6 WATERSHED PATTERN AND CHANGES IN LAND USE IN THE MIN RIVER WATERSHED, FUJIAN[8]

6.1 INTRODUCTION

Watersheds provide a useful geographical scale for the sustainable management of natural resources. Quantifying watershed landscape patterns and land-use changes over time is a key to understanding regional ecosystem well-being and land-use sustainability. Remotely-sensed imagery is ideally suited for describing landscape-scale patterns relative to land-use change by comparing them over times. A number of studies have discussed the use of remote sensing images for land-use classification. Belanger and Grenier (2002) used Landsat images to quantify forest cover in the St. Lawrence Valley, Canada, and associated human population densities and various types of agricultural production with landscape fragmentation. Li *et al*. (2001) used Fragstats to quantify landscape structure in the Heihe River Basin, north-west China, indicating that the landscape pattern of the Heihe River Basin is mainly controlled by the distribution of water patterns. Li *et al*. (2004) used Landsat data to determine land-use change in an arid region of Yulin Prefecture in north-western China. The study showed that integration of remote sensing and Fragstats was an effective approach for detecting regional land-use changes over time. However, most of these studies used only two sets of imagery and were narrowly focused on the changes of the landscape pattern, without considering management practices and land-use policy on the ground, or entering into any detailed discussion of the causes of the land cover changes. The objectives of this study were: 1) to quantify the land-use and land cover changes in the Min River Watershed between 1986 and 2003 using multiple years of Landsat imagery; and 2) to examine the impacts of watershed management practices and changes in land-use policy on the watershed landscape.

6.2 METHODS

6.2.1 Study area

The Min River is located in south-eastern China, between 116°30’ and 119°30’ E and 25°20’ and 28°25’ N. It is the longest river in Fujian Province and one of the ten longest rivers in China. The headwaters of the Min River are situated at an elevation of about 2115 m in the Wuyi Mountains in the north-western section of Fujian. The catchment covers an area of 60,000 km^2. The location of the watershed and research area is shown in Figure 1–1.

The Min River Watershed plays an important role in the social and economic geography of Fujian. Almost one-third of Fujian’s population of approximately 11.9 million people inhabits the watershed. It accounts for over half of the total agricultural production, two-thirds of the

[8] A version of this chapter has been submitted for publication. Wang, G.Y., Innes, J., Liu, L., Yu, K.Y., and Yan, K. Watershed Pattern and change in land-use in the Min River watershed, Fujian. The version presented here differs significantly from the submitted version at the request of the external examiner

commercial logging, and 60% of the drinking water in the province (Fujian Provincial Bureau of Statistics, 2007). As a consequence of the increase in population along the river, the watershed has become intensively used for agriculture, plantations and the construction of infrastructure, leading to the degradation of its ecosystems and widespread soil erosion and sedimentation (Wang *et al*., 2008a). Intensive development has led to the over-cutting of forests in the watershed, resulting in soil erosion, stream sedimentation, flooding and increased run-off. Large clearcuts and burning have caused serious soil erosion and reduced land productivity (Wang *et al*., 2008b), and the natural forest cover has declined significantly over the last 50 years (Zeng *et al*., 2003). The changes have resulted in the annual sand load of the river rising from 7 million tonnes in the 1950s to over 20 million tonnes in the 1990s (Chen, 2000). Since the 1990s, the watershed has been suffering from massive social, economic and environmental damage resulting from flooding, exacerbated by logging in the watershed. The flooding in 1998 alone cost the province US$ 1.2 billion, including both direct and indirect damage (Fujian Chorography Compilation Committee, 2002). Devastating floods or droughts have occurred every year since 2000. An understanding of the relationships between land-use changes, especially between the loss and fragmentation of natural forests and flooding, is crucial for effective forest management in the watershed. Detecting landscape fragmentation over time is an important step in examining this relationship.

6.2.2 Spatial data acquisition, classification and accuracy analysis

Landsat Thematic Mapper imagery (Path, Row: 119–41, 119–42, 120–41, and 120–42) was acquired for the watershed for 1986, 1990, 2000 and 2003. Contour maps (1:50 000), a political boundary map (vector, 1:250 000), and the 5th (1998) and 6th (2003) Fujian province-wide forest inventory data were also used in this study.

ERDAS software (Leica Geosystems) was used to combine bands, match histograms and merge the images. The contour maps were used for geo-correction, with an overall error of 0.576 pixels. The corrected 1986 images were used to rectify the 1990, 2000 and 2003 images, with the total errors being 0.042, 0.076, and 0.052 pixels. Standardization, radiation rectification, and linear stretch were used to enhance the quality of the images, and the logarithm residual method (Okada et al., 1993; ERDAS 2007) was used to reduce the impact of the atmosphere on the pixels. The 2003 corrected image was then used to establish a classified template and histogram matching was used to classify the rest of images.

The images were classified into ten cover types based on the Chinese national land-use classification standards – arable land (mainly rice paddies and vegetable fields), water bodies, orchards (fruit, tea and non-timber forests), conifer forest (mainly firs and pines), broadleaf forest (evergreen broadleaf forest), other forests, grassland, transportation corridors, built-up areas and unused land. Cutblocks, barren land suitable for afforestation, newly forested land and tree nurseries were classified as “other forests” in order to eliminate possible classification errors associated with their identification.

A combination of expert classification, supervised classification and stratified classification was applied to the images (ERDAS, 2007). An expert system was developed to use the TM band

4/band 3 ratio to classify vegetation, non-vegetation and water bodies. Stratified classification was used to eliminate the differences between natural features and to separate the natural feature masks. After extracting the vegetation information, the 6th province-wide forest inventory data and GPS geo-coordinates were used to develop training areas to classify the conifer, broadleaf and other forests. The transportation corridors, built-up areas and unused lands were determined by eye to develop training areas. After matching the histograms 1986, 1990 and 2000 using the 2003 corrected images, all the spectral characteristics were similar. Consequently, expert classification was used to classify water bodies, vegetation and non-vegetation. The 2003 classified template was used to classify the conifer, broadleaf, other forests, orchard, grassland and arable land, and supervised classification was used to classify the transportation corridors, built-up areas and unused land.

After the classification, the 1986 Nanping Forest Inventory, and the 5th (1998) and 6th (2003) Fujian Provincial Forest Inventory data were used to assess the classification accuracy. As permanent plot data are considered to be classified information in China, we could only obtain 20% of the data. 386 stratified and randomly selected permanent plots from the 5th (1998) inventory and 297 plots from the 6th (2003) inventory, and 100 plots of each class from the permanent plots of the 1986 Nanping Forest Inventory were used for the accuracy analysis,. The accuracy was calculated by comparing the results from a digital classification to the known identity with ground true information (Treitz *et al*., 1992).

6.2.3 Landscape quantification

Fragstats 3.3 software was used to calculate landscape metrics for the 1986, 1990, 2000, and 2003 classified images. Fragstats was used because: 1) it is free; 2) the software can directly import classified files from ArcGIS without further transformation, and 3) it computes a wide variety of metrics. Although Fragstats software can calculate more than 100 metrics (Griffith *et al*., 2000), many are highly correlated, reducing their potential usefulness (Apan *et al*., 2002). Riitters *et al*. (1995) examined the correlations among 55 different landscape metrics by factor analysis and identified only five independent factors. As many metrics are strongly correlated with one another, containing redundant information (Turner *et al*., 2001), factor analysis was used to identify the principal components accounting for as much of the variability in the data as possible. SAS (SAS system for Window, 9.1.3 SAS Institute Inc., Cary, NC, USA, 2005) was used for this analysis. Based on the objectives of the landscape quantification (to examine the fragmentation of forests and the dynamic of the land cover changes), factor analysis was used to examined the potential overlap of the metrics (for details see the results section).

As Fragstats software requires 250 m × 250 m raster 16-bit signed integer grids containing all non-zero class values (Fragstats User Guidelines, 2007), the images from the four years were transferred into the required format and run under the Fragstats 3.3 program. The 250 m × 250 m grid creates cells of 6.25 ha, about the size of a stand sub-compartment or a typical agricultural unit in a small valley in the study area.

6.2.4 Identification of the impact of land-use change

The social and economic development data of the Min Watershed from 1990, 2000, and 2003 were derived from the Fujian Statistic Yearbook (Fujian Provincial Bureau of Statistics, 1990, 2000, and 2003) to identify the impact of land-use change on the watershed. The data also include population growth over the periods and the government policy towards watershed development. The comparison of the landscape quantification data and statistical data reveals the dynamics of land-use change and the mechanisms of those changes.

6.3 RESULTS AND DISCUSSION

6.3.1 Accuracy assessment

After the classification, the group truth data was selected to conduct accuracy analysis. Due to the limited resources available, we randomly selected 386 permanent plots from the 5th (1998) Fujian Forestry Continuous Inventory Database and 297 plots from the 6th (2003) Fujian Forestry Continuous Inventory Database, and 100 plots of each class from the permanent plots of the 1986 the Nanping Forest Inventory Database. The results are shown in Tables 6–1, 6–2, and 6–3. Overall Kappa values in 1986, 2000, and 2003 derived from the error matrix are 0.822, 0.833 and 0.856 respectively. The confusion matrixes of the three assessments are listed in Tables 6–4, 6–5 and 6–6.

Table 6-1. 2003 Accuracy Assessment. (Overall Classification Accuracy = 87.9%, Overall Kappa Statistics = 0.865).

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	User Accuracy
Arable land	39	42	35	89.7	83.3
Water body	8	7	7	87.5	100
Built-up area	18	18	16	88.9	88.9
Orchard	25	24	22	88.0	91.7
Conifer	119	114	105	88.2	92.1
Broadleaf	45	46	40	88.9	87.0
Other forests	9	11	8	88.9	72.7
Grassland	8	10	7	87.5	70.0
Transportation	15	16	13	86.7	81.3
Unused land	11	9	8	72.7	88.9
Totals	297	297	261		

Table 6-2. 2000 Accuracy Assessment. (Overall Classification Accuracy = 84.5%, Overall Kappa Statistics = 0.833).

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	User Accuracy
Arable land	45	43	37	82.2	86.1
Water body	12	10	10	83.3	100
Built-up area	17	18	16	94.1	88.9
Orchard	42	49	41	97.6	83.7
Conifer	132	139	112	84.9	80.6
Broadleaf	78	80	68	87.2	85.0
Other forests	28	18	16	57.1	88.9
Grassland	15	13	12	80.0	92.3
Transportation	9	9	8	88.9	88.9
Unused land	8	7	6	75.0	85.7
Totals	386	386	326		

Table 6-3. 1986 Accuracy Assessment. (Overall Classification Accuracy = 84%, Overall Kappa Statistics = 0.822).

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	User Accuracy
Arable land	12	10	9	75.0	90
Water body	7	10	7	100	70
Built-up area	10	10	9	90.0	90
Orchard	9	10	7	77.8	70
Conifer	13	10	10	76.9	100
Broadleaf	9	10	9	100	90
Other forests	8	10	8	100	80
Grassland	10	10	8	80.0	80
Transportation	11	10	9	81.8	90
Unused land	11	10	8	72.7	80
Totals	100	100	84		

Table 6-4. 2003 Confusion Matrix.

Class Name	Arable land	Water body	Built-up area	Orchard	Conifer	Broadleaf	Other forests	Grassland	Transportation	Unused land
Arable land	35	0	0	1	3	0	0	0	0	0
Water body	0	7	1	0	0	0	0	0	0	0
Built-up area	0	0	16	0	0	0	1	0	1	0
Orchard	1	0	0	22	0	2	0	0	0	0
Conifer	5	0	0	1	105	4	1	2	1	0
Broadleaf	1	0	0	0	4	40	0	0	0	0
Other forests	0	0	0	0	1	0	8	0	0	0
Grassland	0	0	0	0	1	0	0	7	0	0
Transportation	0	0	1	0	0	0	0	0	13	1
Unused land	0	0	0	0	0	0	1	1	1	8

Table 6-5. 2000 Confusion Matrix.

Class Name	Arable land	Water body	Built-up area	Orchard	Conifer	Broadleaf	Other forests	Grassland	Transportation	Unused land
Arable land	37	0	1	0	6	0	0	0	0	1
Water body	0	10	1	1	0	0	0	0	0	0
Built-up area	0	0	16	0	0	0	0	0	1	0
Orchard	0	0	0	41	0	0	0	1	0	0
Conifer	4	0	0	5	112	11	0	0	0	0
Broadleaf	0	0	0	1	9	68	0	0	0	0
Other forests	0	0	0	1	10	1	16	0	0	0
Grassland	1	0	0	0	2	0	0	12	0	0
Transportation	0	0	0	0	0	0	1	0	8	0
Unused land	1	0	0	0	0	0	1	0	0	6

Table 6-6. 1986 Confusion Matrix.

Class Name	Arable land	Water body	Built-up area	Orchard	Conifer	Broadleaf	Other forests	Grassland	Transportation	Unused land
Arable land	9	0	0	2	0	0	0	0	0	1
Water body	0	7	0	0	0	0	0	0	0	0
Built-up area	0	0	9	0	0	0	0	0	1	0
Orchard	0	0	0	7	0	0	0	1	0	1
Conifer	0	0	0	0	10	1	2	0	0	0
Broadleaf	0	0	0	0	0	9	0	0	0	0
Other forests	0	0	0	0	0	0	8	0	0	0
Grassland	1	1	0		0	0	0	8	0	0
Transportation	0	1	1	0	0	0	0	0	9	0
Unused land	0	1	0	1	0	0	0	1	0	8

6.3.2 Landscape metrics selection and analysis

Based on the objectives of the study, we selected 46 relevant metrics in both landscape and class levels. A factor analysis (using SAS 9.2 software) was used and a Scree test was conducted to select the metrics with eigenvalues greater than one (cutoff value) (Jackson, 1993). The result (Figure 6–1) indicated that only four metrics had eigenvalues greater than one. Factor Analysis also showed that some of the metrics are identical (perfect correlation), and most of them are highly related to one another.

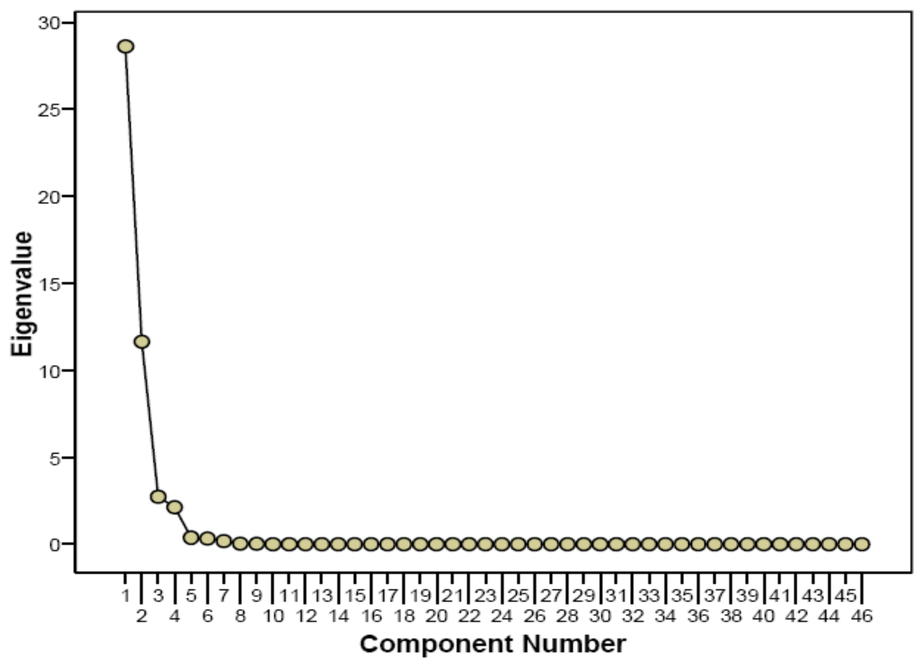


Figure 6-1. Scree Plot for the 46 metrics in the Scree test.

Based on the objectives of the research and a Varimax rotation of the factor analysis on the class level metrics, only the metrics listed in Table 6–7 contributed to the main factors.

Table 6-7. Fragstats metrics included in the analysis.

Levels	Abbreviation	Metrics name
Landscape (10)	LPI	Largest patch index
	NP	Number of patches
	MPS	Mean patch size
	ED	Edge density,
	AWMSI	Area-weighted mean shape index
	AWMPFD	Area-weighted mean patch fractal dimension
	MNND	Mean nearest-neighbour distance
	SDI	Shannon's diversity index
	IJI	Interspersion and juxtaposition index, and
	CI	Contagion index
Class (14)	TCA	Total class area
	PLAND	Percent of landscape
	NP	Number of patches
	PD	Patch density
	LPI	Large patch index
	TE	Total edge
	ED	Edge density
	LSI	Landscape shape index
	AREA_MN	Mean patch area distribution
	SHAPE_MN	Mean shape index distribution
	PARA-MN	Mean perimeter-area ratio distribution
	CONTIG_MN	Mean contiguity index distribution
	PAFARC	Perimeter-area fractal dimension
	IJI	Interspersion and juxtaposition index

Based on the landscape metrics analysis (Table 6-8, 6-9 and 6-11), below concludes the major development of the six land use types:

1) Built-up areas: there has been a rapid increase in built-up areas (cities, towns and villages). Existing cities and towns have greatly expanded and, at the same time, many new small towns and villages have been developed. The number of patches classified in this category has doubled since 1986.
2) Orchards: non-timber forests have increased significantly throughout the study period, with an annual increase of 7% in area, and a total increase of 129% over the 1986 value. Orchards are expanding from flat ground to mountain areas.
3) Conifer forest: conifer plantations are one of the fastest growing forms of land use in the watershed. The increase of LPI, TE and ED and decrease in patch number and density indicate that the size of individual plantations is increasing.
4) Broadleaf forest: 25% of the broadleaf forest in the watershed was lost between 1986 and 2000. An increase in the number of patches and a decrease in the large patch index indicate that the forest is becoming fragmented. Since 2000, the area of broadleaf forest has increased slightly in the watershed.
5) Grassland and unused land: the matrices for these two classes have the same trend, with a substantial decrease in area, patch number and density. This suggests that these forms of land use are disappearing in the watershed. The total numbers of patches of grassland

and unused land have declined from 39,644 and 44,174 to 9,468 and 8,809, respectively.

6) Road building: the results indicate that the transportation system has increased over almost all the indices.

Table 6-8. The general trend of each metric by land-use category.

Class Metric	Arable land	Water body	Built-up area	Orchard	Conifer	Broad leaf	Other forests*	Grassland	Road	Unused land
TCA	D	I	I	I	I	D	I	D	I	D
PLAND	D	I	I	I	I	D	I	D	I	D
NP	I	I	I	I	D	I	I	D	I	D
PD	I	I	I	I	D	I	I	D	I	D
LPI	D	D	I	D	I	D	I	D	I	D
TE	D	I	I	I	I	N	I	D	I	D
ED	D	I	I	I	I	N	I	D	I	D
LSI	N	I	I	I	I	I	I	D	I	D
AREA-MN	D	D	D	I	I	D	I	D	I	D
SHAPE_MN	D	I	D	I	I	D	N	D	I	D
PARA-MN	N	D	I	D	D	N	N	I	N	I
CONTIG_MN	D	I	D	N	I	N	N	D	N	D
PAFARC	N	I	I	I	I	I	N	N	N	D
IJI	D	D	N	D	D	D	D	I	D	I

(D – decrease (>10%), I – increase (10%), and N – No significant change (<1%), – minor change in the general trend with fluctuation during the periods (change between 1–10%))
* Other forest, mainly new plantations, has increased dramatically in the period 1986–2000, but has since decreased as a result of the campaign to eliminate barren land.

At the scale of the landscape, the indices generally point to increasing fragmentation (Table 4–9). Natural landscapes such as broadleaf forest, grassland, and unused land are being lost and/or fragmented, whereas artificial landscapes (urban areas, conifer forest, reservoirs and transportation corridors) are becoming more dominant.

Table 6-9. The general trend in each metric at the landscape level.

Landscape Metric	1986	1990	2000	2003
LPI	1.37	1.04	0.41	0.732
NP	294039	297846	286262	273168
MPS	20.6	20.4	21.2	22.2
ED	31.4	32.0	31.8	31.9
AWMSI	7.19	5.89	6.56	7.26
AWMPFD	1.13	1.12	1.14	1.14
MNND	645	645	661	655
SDI	1.99	1.98	1.91	1.83
IJI	83.6	83.1	80.2	75.2
CI	16.9	16.7	19.3	22.7

6.3.3 Forest land change and associated policy changes in the last twenty years

It is evident from Table 6–10 (the changes in the ten land cover types between 1986 and 2003) and Figure 6–2 (the percentage of land cover changes in the four detection periods) that the overall forested area has increased by over 468,000 ha. since 1986, but the area of natural forest has been depleted by about 427,000 ha. This represents a reduction of 25% in the total area of natural forest present in 1986. The area of plantations, mainly conifers, has increased from 1.29 million ha. to 2.18 million ha, increasing by 68%, and accounting for 55.1% of total the forest land (conifer, broadleaf and other forests) in the watershed.

Several government policies appear to be contributing to land degradation in the watershed. More than 100 logging farms have been established since 1956 in the upper reaches of the watershed, and these are the main driver of the observed loss of 30,000 ha. of natural forest. The logging farms officially stopped logging natural forests after 1998, and since then have been turned into tree farms.

There was a substantial increase in the area of conifer plantations and 456,198 ha. of new forest was established between 1986 and 1990 under the Greening Barren Land Program (1987–1993). In contrast, the area of broadleaf forest has decreased by about 171,000 ha. The Greening Barren Land Program resulted in large areas of grassland (wetland) being converted to forest.

Since 1994, this change has been accelerated by the booming forest industry, which has created a strong demand for poplar and eucalyptus forests. The industry, consisting of paper mills, wood-based panel and fiberboard plants, has placed heavy pressure on the land (Chen, 2000a), and the transition matrix demonstrates that more and more natural forest, grassland and unused land, and even arable land, is being converted to fast-growing, high-yield plantations. This presents a conundrum for a country where sustainable forest management is favoured but within a suitable economic and political context (c.f. Liu, 2007).

After implementing the Nationwide Natural Forest Protection Program in 1998 and the Ecological Forest Compensation Program in 2000, natural forest (broadleaf forest) has been protected and the area of this forest type has been gradually increasing.

6.3.4 Detection of land-use and land-cover dynamic changes

The watershed change matrices reflect the rapid development that has occurred over the last two decades in the Min watershed, with economic development taking precedence over any attempt to conserve natural resources or protect the environment.
The land-cover transition matrix (Table 6–11) sheds light on the dynamic changes that are occurring:

1) One of the main policies to increase farmers' income in rural areas is to develop orchard and non-timber forests under the provincial government's Agricultural Multiple Management programs, associated with the Household Responsibility Systems introduced in 1982. Financial incentives have been available from the provincial government since 1984, and the area of orchards (including non-timber forests) in the Min River Watershed resulted in the conversion of many foothills forests to orchards. The area of land devoted to orchards has increased from 6% of the total watershed in 1986 to 13.3% in 2003.
2) The reduction in the area of grassland amounts to about 387,000 ha, or 85% of the area present in 1986, which largely consisted of wetlands along the Min River. Some of this loss can be attributed to the development of intensive livestock husbandry since 1999 which has increased the use of wetlands and riparian areas in the watershed. The development of dams and a significant poultry industry along the river bank have also contributed to the loss. The loss of the grassland has already created ecological problems, such as an outbreak of the invasive weed *Eichhornia crassipes* along the river. Several millions of dollars have been spent, but the expansion of the species has not been controlled. Grassland areas on mountain tops have also been shrinking, and forest encroachment in such areas is evident.
3) The construction of large-scale infrastructure projects, such as roads (46% increase in area since 1986) and housing developments (77% increase in area since 1986) is significant. A wave of urbanization has led to massive housing development along the river, and entire new cities, such as Jiangou, Jiangyang, Sanming, and Shaxian have been developed. About five million people inhabiting the basin are now at risk from flooding.
4) The development of hydropower has gradually increased the area covered by water bodies, which have increased by 49% since 1986. The resulting rises in water levels have contributed to several floods in Nanping and Jian-ou cities by slowing the discharge of floodwater through the cities (Zeng et al., 2003).
5) Although the government has called for the area of agricultural land to be maintained (China State Council 1986, 1997, and 2008), it has decreased by 104,500 ha, a 16% reduction since 1986. This has mainly occurred through the expansion of built-up areas, the development of the road system, and the development of orchards.

6) The area of unused land has been reduced by 651,500 ha, and 90% now has some form of land use. Most of the land that was classified as unused in 1986 was located on steep slopes which are now forested, whereas rocky areas along the main river have been exploited for construction material.

Comparison the land cover change report from Heihe, Northwest China (Qi and Luo, 2006), the two patterns of changes are much different in cropland and water body from the Min River, due to the arid condition and less developed economy, the cropland is increasing, while water body is decreasing. However, the similarity to the recent global land use and land cover change synthesized by Lambin and Geist (2006) that several land classes' development trends, e.g., arable land, build-up, nature forest, grassland and transportation are similar, while water body, orchard, conifer and unused land are slightly in different direction.

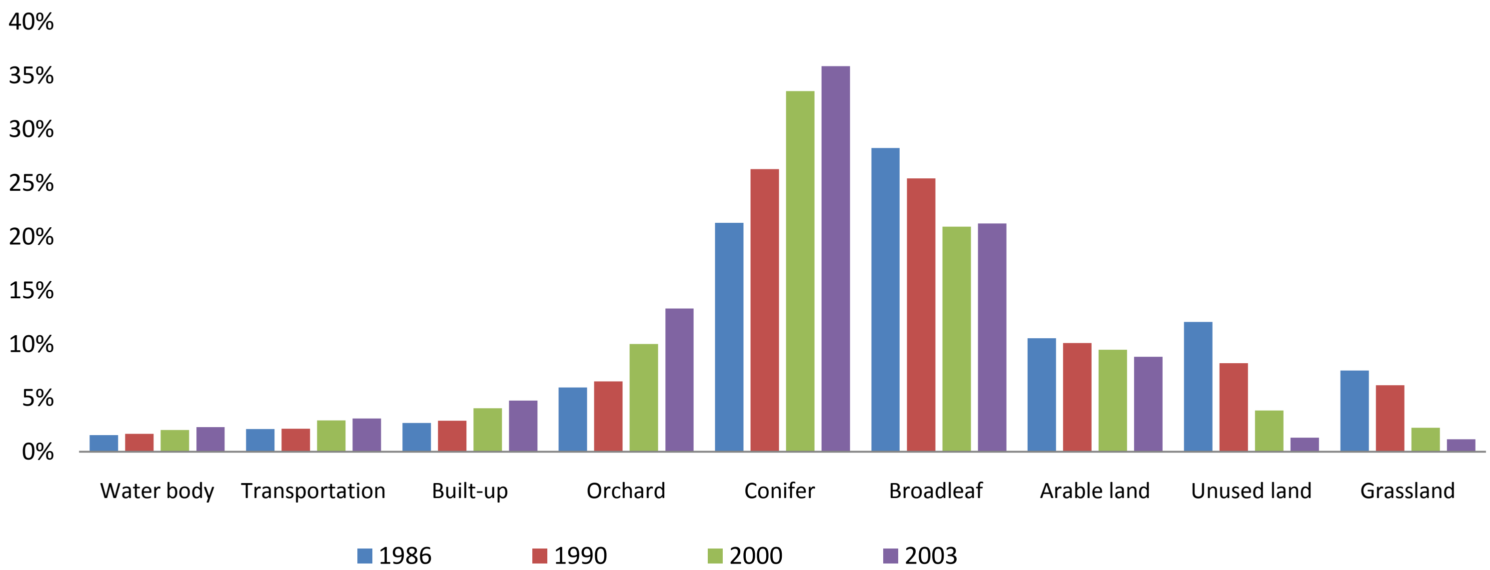


Figure 6-2. Land cover changes in the four detected periods.

Table 6-10. Changes in the ten land cover types between 1986 and 2003. Units are in hectares.

Year	Arable land	Water body	Built-up	Orchard	Conifer	Broad leaf	Other forests	Grassland	Transportation	Unused land
1986	640370	93843	163375	363606	1293009	1714230	482981	457590	128648	731850
1990	614412	101297	174608	397698	1595154	1543131	637034	375107	130118	500942
2000	576015	123057	245891	608250	2037022	1271732	662336	136024	176966	232208
2003	535698	139622	288402	808566	2176646	1289268	492663	70362	188113	80161

Table 6-11. Analysis of land cover transition matrix.

Year	Class name	Arable land	Water body	Built-up	Orchard	Conifer	Broad-leaf	Other forests	Grassland	Transport-ation	Unused land
1986–1990	Arable land	0.9256	0.0003	0.0037	0.0036	0.0385	0.0089	0.0057	0.0025	0.0001	0.0111
	Water body	0.0002	0.9965	0.0011	0.0000	0.0003	0.0000	0.0001	0.0000	0.0000	0.0017
	Built-up	0.0000	0.0000	0.9998	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002
	Orchard	0.0120	0.0002	0.0002	0.9240	0.0332	0.0007	0.0087	0.0079	0.0000	0.0130
	Conifer	0.0192	0.0005	0.0007	0.0095	0.8129	0.0301	0.0544	0.0396	0.0001	0.0329
	Broadleaf	0.0036	0.0002	0.0001	0.0019	0.0267	0.9378	0.0171	0.0078	0.0000	0.0047
	Other forests	0.0069	0.0004	0.0003	0.0130	0.1481	0.0032	0.7589	0.0374	0.0000	0.0318
	Grassland	0.0000	0.0007	0.0000	0.0139	0.1653	0.0030	0.0577	0.7105	0.0001	0.0488
	Transportation	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9940	0.0060
	Unused land	0.0000	0.0015	0.0000	0.0112	0.1542	0.0017	0.0475	0.0242	0.0003	0.7594
1986–2000	Arable land	0.9640	0.0014	0.0040	0.0036	0.0117	0.0041	0.0031	0.0008	0.0021	0.0052
	Water body	0.0046	0.9666	0.0020	0.0027	0.0107	0.0026	0.0018	0.0009	0.0029	0.0052
	Built-up	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Orchard	0.0041	0.0003	0.0004	0.9778	0.0096	0.0009	0.0038	0.0006	0.0011	0.0014
	Conifer	0.0057	0.0010	0.0010	0.0059	0.9635	0.0062	0.0110	0.0023	0.0005	0.0028
	Broadleaf	0.0005	0.0001	0.0001	0.0023	0.0157	0.9737	0.0062	0.0008	0.0001	0.0005
	Other forests	0.0025	0.0004	0.0005	0.0063	0.0396	0.0012	0.9453	0.0021	0.0003	0.0019
	Grassland	0.0044	0.0009	0.0004	0.0077	0.0387	0.0016	0.0119	0.9310	0.0007	0.0027
	Transportation	0.0037	0.0006	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9956	0.0000
	Unused land	0.0064	0.0026	0.0014	0.0066	0.0336	0.0014	0.0072	0.0035	0.0010	0.9363

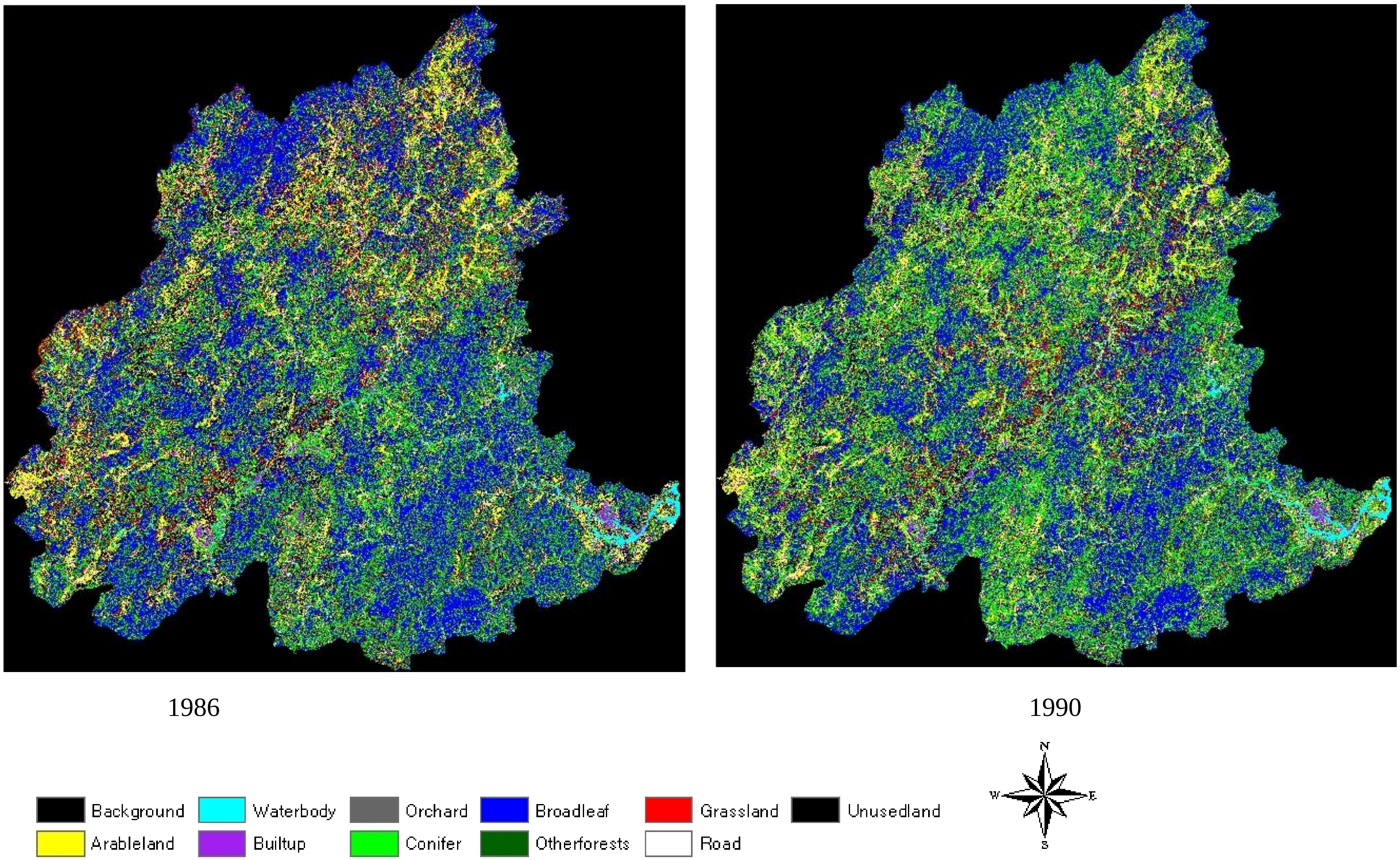
Table 6–11. Analysis of land cover transition matrix (Cont.)

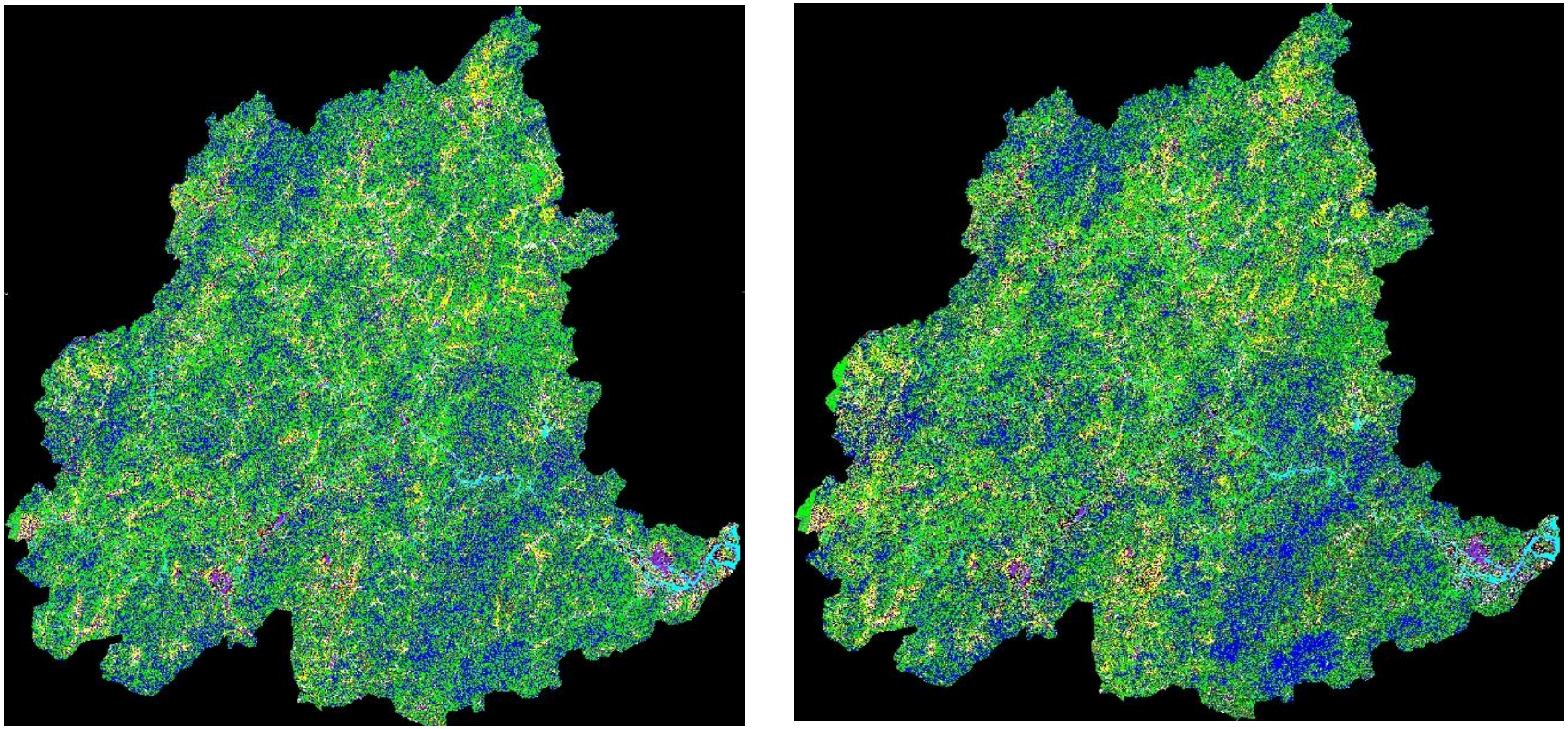
Year	Class name	Arable land	Water body	Built-up	Orchard	Conifer	Broad Leaf	Other forests	Grassland	Transport -ation	Unused land
1986–2003	Arable land	0.9657	0.0017	0.0045	0.0051	0.0121	0.0043	0.0012	0.0010	0.0018	0.0027
	Water body	0.0041	0.9734	0.0025	0.0025	0.0074	0.0027	0.0010	0.0010	0.0031	0.0024
	Built-up	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Orchard	0.0033	0.0003	0.0006	0.9773	0.0122	0.0031	0.0016	0.0004	0.0009	0.0004
	Conifer	0.0044	0.0010	0.0013	0.0078	0.9690	0.0086	0.0061	0.0007	0.0004	0.0006
	Broadleaf	0.0007	0.0001	0.0002	0.0045	0.0181	0.9704	0.0058	0.0001	0.0001	0.0001
	Other forests	0.0022	0.0004	0.0007	0.0083	0.0316	0.0063	0.9495	0.0005	0.0002	0.0003
	Grassland	0.0045	0.0008	0.0007	0.0090	0.0302	0.0068	0.0051	0.9419	0.0006	0.0004
	Transportation	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
	Unused land	0.0059	0.0027	0.0019	0.0070	0.0261	0.0058	0.0046	0.0021	0.0009	0.9431
1990–2000	Arable land	0.9576	0.0015	0.0051	0.0036	0.0137	0.0055	0.0039	0.0007	0.0026	0.0057
	Water body	0.0068	0.9501	0.0025	0.0040	0.0168	0.0042	0.0028	0.0013	0.0042	0.0073
	Built-up	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Orchard	0.0026	0.0002	0.0003	0.9840	0.0068	0.0010	0.0025	0.0004	0.0017	0.0006
	Conifer	0.0120	0.0017	0.0019	0.0071	0.9501	0.0026	0.0162	0.0029	0.0010	0.0046
	Broadleaf	0.0002	0.0001	0.0001	0.0026	0.0147	0.9751	0.0060	0.0007	0.0001	0.0004
	Other forests	0.0007	0.0007	0.0008	0.0054	0.0597	0.0016	0.9244	0.0031	0.0004	0.0031
	Grassland	0.0000	0.0014	0.0000	0.0057	0.0659	0.0023	0.0163	0.9046	0.0004	0.0034
	Transportation	0.0053	0.0010	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.9937	0.0000
	Unused land	0.0000	0.0045	0.0000	0.0079	0.0504	0.0022	0.0116	0.0070	0.0014	0.9149

Table 6–11. Analysis of land cover transition matrix (Cont.)

Year	Class name	Arable land	Water body	Built-up	Orchard	Conifer	Broad leaf	Other forests	Grassland	Transport-ation	Unused land
1990–2003	Arable land	0.9578	0.0018	0.0057	0.0064	0.0153	0.0054	0.0016	0.0009	0.0021	0.0030
	Water body	0.0057	0.9628	0.0031	0.0036	0.0109	0.0041	0.0015	0.0013	0.0041	0.0029
	Built-up	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Orchard	0.0023	0.0001	0.0004	0.9795	0.0118	0.0026	0.0016	0.0002	0.0013	0.0001
	Conifer	0.0086	0.0016	0.0023	0.0091	0.9596	0.0083	0.0076	0.0012	0.0008	0.0010
	Broadleaf	0.0006	0.0002	0.0002	0.0051	0.0199	0.9673	0.0066	0.0001	0.0001	0.0000
	Other forests	0.0017	0.0007	0.0011	0.0087	0.0429	0.0082	0.9352	0.0008	0.0003	0.0004
	Grassland	0.0022	0.0012	0.0001	0.0093	0.0453	0.0091	0.0080	0.9240	0.0003	0.0005
	Transportation	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
	Unused land	0.0037	0.0039	0.0004	0.0082	0.0377	0.0085	0.0063	0.0036	0.0011	0.9267
2000–2003	Arable land	0.8687	0.0051	0.0168	0.0303	0.0540	0.0138	0.0059	0.0000	0.0052	0.0000
	Water body	0.0018	0.9327	0.0021	0.0079	0.0336	0.0108	0.0055	0.0000	0.0057	0.0000
	Built-up	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Orchard	0.0326	0.0009	0.0015	0.8834	0.0603	0.0116	0.0097	0.0000	0.0000	0.0000
	Conifer	0.0114	0.0041	0.0011	0.0331	0.8727	0.0338	0.0437	0.0000	0.0000	0.0000
	Broadleaf	0.0042	0.0009	0.0002	0.0140	0.0583	0.9040	0.0184	0.0000	0.0000	0.0000
	Other forests	0.0147	0.0011	0.0011	0.0384	0.1779	0.0513	0.7155	0.0000	0.0000	0.0000
	Grassland	0.0074	0.0000	0.0000	0.0307	0.1752	0.0327	0.0437	0.7032	0.0000	0.0071
	Transportation	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
	Unused land	0.0118	0.0000	0.0000	0.0183	0.0784	0.0184	0.0159	0.0796	0.0000	0.7776

The four classified maps are presented in Figure 6–3. The changes in forest cover are particularly apparent. In 1986, broadleaf forest was concentrated in the two main mountain ranges in Fujian: Wuyi Mountain (in the northwest corner, extending from northeast to southwest) and Daiyun Mountain (in the lower centre, extending from northeast to southwest). However, large patches of broadleaf forests and wetland have been lost, replaced by conifer forest.


1986
1990
Background
Waterbody
Orchard
Broadleaf
Grassland
Unusedland
Arableland
Builtup
Conifer
Otherforests
Road
N
W
E
S



2000 2003

Figure 6-3. Four period classified Landsat image.

6.3.5 The social and economic impact of land use change on the watershed

The statistical data (Table 6–12) of the watershed from Fujian Statistic Yearbooks (Fujian Provincial Bureau of Statistics, 1991, 2001 and 2004) validate the results obtained from the Landsat data analysis, and also suggest that government attempts to promote rural development and thereby increase the overall income of farmers are meeting with some success. Over the last two decades, the GDP growth in industry and services has increased by more than 1000% (Table 6–12). Relatively, agriculture has become less important, and the economic development of the watershed is no longer reliant on agriculture. Rice production has declined 22.6%, whereas production of the three main non-timber products from orchards, edible oil, tea and fruit, increased 203%, 116% and 418%, respectively, during the period. Three rural income indices, namely revenues from farming, forestry, and animal husbandry, have increased 955%, 639%, and 1,151%, respectively.

Together with economic development, urbanization and the establishment of an efficient road network has greatly stimulated socio-economic development and enhanced living standards in the region. However, the dramatic development of the transportation network, particularly the development of freeways since 1997, has increased landscape fragmentation and induced soil erosion, landslides and river sedimentation (Wang, 2008a). The rapid urban expansion towards the river in the Nanping area has significantly increased the risk of flooding.

Table 6-12. Social and economic development in the Min River Watershed since 1990. (Adapted from the Fujian Provincial Bureau of Statistics, 1991, 2001 and 2004).

Indicator	1990	2000	2003	Change*
GDP (100 million Yuan)	197	1295	1733	778%
Agriculture GDP	61.9	220	243	293%
Manufacturing GDP	82.0	554	800	876%
Service GDP	51.0	521	689	1252%
Population (10 thousand)	1006	1093	1110	10.3%
Residential housing	577711	2500321	6102242	956%
Farms income	9434	40708	46768	396%
Fiscal income	210230	686224	902987	330%
Fiscal expenditure	165114	789606	1062484	543%
Arable land	817	544	531	-35.0%
Farming revenue	180546	1673702	1904565	955%
Forestry revenue	76502	563164	565478	639%
Animal husbandry revenue	66923	695784	837377	1151%
Rice production	4104941	3702485	3178864	-22.6%
Edible oil production	17787	45279	53925	203%
Tea production	25418	46785	53781	112%
Fruit production	324522	1296150	1680364	418%
Total road density (km/100 km^2)	32.9	44.1	45.5	38.2%

*(The percentage of the change is 1990 vs. 2003)

6.3.6 The comparison of statistical data and the Landsat-derived data

A comparison of the land-use classification data with the limited existing statistical data (Zeng et al, 2003) reveals that the overall statistics being provided by the government are reliable (Figure 6–4). However, there are several differences between the two data sets. In the statistical data, the classification of some grassland as unused land, a failure to include the new (federally-owned) freeway in the local transportation network, confusion over the classification of orchards (orchards managed by the Forest Department are classified as non-timber forests, while those managed by the Agriculture Department are classified as orchards), and a failure to report all urban development (partly for political reasons) mean that there are issues with the data.

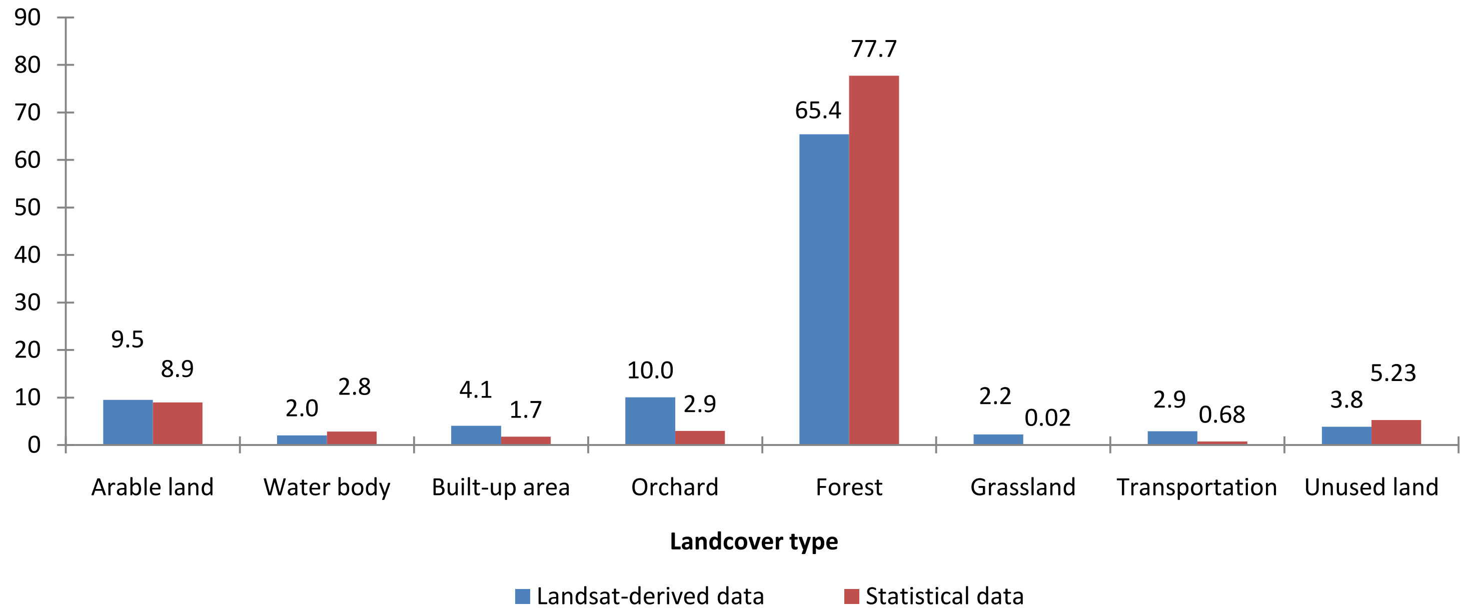


Figure 6-4. The comparison of the ground survey data in 2000 with the Landsat-derived data for 2000.

6.4 CONCLUSIONS AND SUGGESTIONS

Since the 1980s, rapid economic development and population growth have led to major land-use changes in the Min watershed. The increase in human activities has resulted in the depletion of arable land, wetland and natural forest, and an increase in plantations, orchards, and built-up areas. The land use pattern changes have explained the recent social economic outcomes in the watershed. The diverse agriculture income patterns –reduction of the rice production and increase of the productions of livestock, edible oil, tea, and fruit crop have greatly promoted the sustainability of the rural economy. However, the increase of industry and expansion of the urban areas have impacted sustainable development of the watershed. Future action will be needed to achieve a better balance between economic development and the protection of the natural environment.

Detecting patterns and change in land use over time is very important in determining regional ecosystem well-being and land-use sustainability. Current existing computer tools, such as GIS mapping methods (e.g., ARC/GIS), and remote sensing imagery classification tools (such as PCI or ENVI), combined with tools to investigate changes in land-use patterns (such as FRAGSTATS) and Factor Analysis, provide the opportunity to detect regional land-use change over time. They provide potentially useful tools for managers to examine watershed development mechanisms and the impacts of watershed practices and policy changes on watershed sustainability, and will likely aid future planning and decision making.

Two improvements need to be considered for future research: 1) Fragstats appears to be a useful tool for the quantification of land-cover change, but the metrics need to be chosen carefully to avoid overlap and redundancy. A weakness of Fragstats is that the program requires an image resolution of 250 by 250 m, so scaling up from the 28.5 by 28.5 m Landsat data involves the loss of some information and can lead to systematic error in the accuracy analysis. 2) The paper only discussed the land cover pattern changes in the watershed scale, further analysis should be made at the different reach levels, due to the significant differences in population and economic development among the reaches.

6.5 REFERENCES

Apan, A.A., Raine, S.R. and Paterson, M.S. 2002. Mapping and analysis of change in the riparian landscape structure of the Lockyer Valley catchment, Queensland, Australia. *Landscape and Urban Planning* 59: 43–57.

Bélanger, L. and Grenier, M. 2002. Agriculture intensification and forest fragmentation in the St. Lawrence Valley, Québec, Canada. *Landscape Ecology* 17: 495–507.

Chen, C.M. 2000. The Min River eco-environment problems analysis. *The Taiwan Strait* 19 (2): 237–243.

Chen, C.M. 2000a. The impact of the industrial structure and distribution on environment around Min river basin. *Journal of Fujian Geography* 15(1), 14–17.

China State Council 1993. China National Land Use Planning Outline (1986-2000). Xinhua News Agency Outlook Weekly. http://lw.xinhuanet.com/htm/content_3527.htm

China State Council 1997. China National Land Use Planning Outline (1997-2010). The Ministry of Land and Resources of China. http://www.mlr.gov.cn/zwgk/ghjh/200710/t20071017_88615.htm

China State Council 2008. China National Land Use Planning Outline (2006-2020).Xinhua *News* Agency. http://news.xinhuanet.com/newscenter/2008-10/23/content_10241429.htm

ERDAS 2007. *ERDAS Field Guide*. Leica Geosystems Geospatial Imaging. www.gi.leica-geosystems.com/LGISub2x514x0.aspx

FRAGSTATS User Guidelines and Software, version 3.3. Accessed Dec.2007. http://www.umass.edu/landeco/research/fragstats/documents/User%20guidelines/User%20guidelines%20content.htm.

Fujian Chorography Compilation Committee 2002. *Fujian Chorography*. Fangzi Publishing: Fuzhou.

Fujian Provincial Bureau of Statistics 1991, 2001, 2003 and 2007. *Fujian Statistical Yearbook*. Fujian Provincial Bureau of Statistics: Fuzhou.

Gergel, S.E. and Turner, M.G. 2001. *Learning Landscape Ecology: A practical guide to concepts and techniques*. Springer: New York.

Griffith, J.A., Martinko, E.A. and Price, K.P. 2000. Landscape structure analysis of Kansas at three scales. *Landscape and Urban Planning* 53: 45–61.

Jackson, D.A. 1993. Stopping rules in principal components analysis: A comparison of heuristical and statistical approaches. *Ecology* 74(8): 2204–2214.

Okada, K., Segawa, K. and Hayashi, I.. 1993. Removal of the vegetation effect from landsat TM and GER imaging spectroradiometer data. *J. Photogram. Remote Sensing*, 48: 16–27.

Lambin, E. F. and Geist, H. 2006. *Land-Use and Land-Cover Change: Local Processes and Global Impacts*. Springer: Berlin Heidelberg. pp21-28.

Li, X., Lu, L., Cheng, G.D. and Xiao, H. L. 2001. Quantifying landscape structure of the Heihe River Basin, Northwest China using FRAGSTATS. *Journal of Arid Environments* 48: 521–535.

Li, Z., Li, X., Wang, Y., Ma, A. and Wang, J. 2004. Land-use change analysis in Yulin Prefecture, Northwestern China using remote sensing and GIS. *International Journal of Remote Sensing* 25 (24): 5691–5703.

Liu, J.L. 2007. Contextualizing forestry discourses and normative frameworks towards sustainable forest management in contemporary China. *International Forestry Review* 9(2): 653–660.

Qi, S.Z. and Luo, F. 2006. Land-use change and its environmental impact in the Heihe River

Basin, Arid northwestern China. *Environ Geol.* 50: 535-540.
Ritters, K.H., O'Neill, R.V., Hunsaker, C.T., Wickham, J.D., Yankee, D.H., Timmons, S.P., Jones, K.B. and Jackson, B. L. 1995. A factor analysis of landscape pattern and structure metrics. *Landscape Ecology* 10: 23–40.
Treitz, M. P., Howarth, J. P. and Gong, P. 1992. Application of satellite and GIS technologies for land cover and land-use mapping at the rural urban fringe: A case study. *Photogrammetric Engineering and Remote Sensing* 60 (3): 331–337.
Turner, M.G., Gardner, R.H. and O'Neill, R.V. 2001. *Landscape Ecology in Theory and Practice: Pattern and Process*. Springer: New York.
Wang, G.Y. and Innes, J.L. 2005. Watershed sustainability: Strategic and tactical level assessment in the Min River Watershed, China. *Environmental Informatics* 3:76–83.
Wang, G.Y., Innes, J.L., Yang, Y.S., Chen, S.M., Xie, J.S. and Lin, W.L. 2008. Extent of soil erosion associated with large-scale infrastructure development and possible amelioration measures. *Catena*. Submitted.
Wang, G.Y., Innes, J.L., Hong, W., Ma, X.Q., Lin, S. Z. and Zhu, W. 2008b. Soil erosion associated with the establishment of Chinese fir plantations in southeast China. *Canadian Journal of Forest Research.* Submitted.
Zeng, C.S., Tang, X.H. and Wang, J.K. 2003. *The investigation report on status quo of Fujian ecological environment.* China Environmental Science Press: Beijing.

7 EXTENT OF SOIL EROSION ASSOCIATED WITH LARGE-SCALE INFRASTRUCTURE DEVELOPMENT AND POSSIBLE AMELIORATION MEASURES[9]

7.1 INTRODUCTION

The widespread occurrence of soil erosion could limit the sustainable development of Chinese society and the Chinese economy (e.g., Chen, 2000; Wang, 2003; Wang *et al*., 2008). Construction activity can increase the erosion from an area by a factor of up to 40,000, and the subsequent sediment can adversely affect surface water quality (Harbor, 1999; Edward and Burina, 2002) and include the obstruction of waterways. In the USA, the effects of soil erosion and sedimentation on streams, lakes and wetlands are well documented (e.g., Booth, 1990). Specific erosion control measures at construction sites have also been evaluated (Barrett et al., 1995a, 1995b, 1998; Price and Brige, 2005). Although minor in comparison to the total quantities of sediment generated from agricultural areas, individual construction sites can contribute massive loads of sediment to small areas in short time periods (e.g., Kaufman, 2000).

Rapid economic development in China over the last 20 years has resulted in major infrastructure development, potentially the largest human disturbance of the land in Chinese history. The construction has altered landforms, vegetation and waterways, and has led to water and soil erosion, sedimentation and land degradation. However, a lack of economic incentives for land developers in China, combined with a lack of research in China and insufficient regulations to control erosion, has limited the adoption of erosion and sediment control measures. Soil erosion from construction sites and its impacts are poorly documented and generally underestimated in China, partly because of the centralized planning and control systems, and issues surrounding criticism of government-funded infrastructure projects. For example, Jiao (1998) has pointed out that between 1991 and 1995 in China, the annual amount of soil and rock displaced by construction exceeded 3 billion tonnes annually. In the middle and upper reaches of the Yangtze River, the annual increase in area impacted by erosion has been over 1200 km^2 (Wang, 2003) In the Three Gorges area alone, 127 construction projects resulted in more than 0.1 billion tonnes of soil being released into the river (Wang, 2003). In Shaanxi province, the area impacted by soil erosion caused by road building (freeways highways and other related construction) has increased by 5278 km^2, representing about 6% of the total area impacted by erosion. Annual soil losses in Shanxi province amount to about 75 million tonnes, predominantly caused by mining and rock exploitation (Jiao, 1998). Similar losses are believed to be occurring in many of the other provinces experiencing rapid infrastructure development.

A variety of temporary measures can be implemented to reduce erosion and to trap sediment on site, such as temporary surface covers, siltation fences, and sedimentation basins. However, the design and implementation of these measures requires an understanding of the important erosion

[9] A version of this chapter 'Extent of soil erosion associated with large-scale infrastructure development and possible amelioration measures' has been accepted for publication in *Catena*. Wang, G. Y., Innes, L. J., Yang, Y.S., Chen, S.M., Xie, J.S. and Lin, W. L. At the request of the external examiner, the version presented here differs significantly from the version that will be published.

and sedimentation processes at a site and, in many cases, incorrect installation and maintenance has limited their effectiveness (Harbor, 1999; Price and Brige, 2005). In this study, the magnitude and distribution of impacts caused by infrastructure construction are estimated for the rapidly-developing province of Fujian.

Fujian lies on the sub-tropical south-eastern coast of China. It has a land area of approximately 120,000 km^2 and has a population of 32.6 million. Fujian's GDP has increased eight-fold since 1980, and it is one of China's most rapidly developing regions (Figure 7–1). In response to this massive economic development, Fujian's infrastructure has been rapidly improved. Projects include a new highway network, a highly developed railway system, a water transportation network, and a number of large and medium-size power stations.

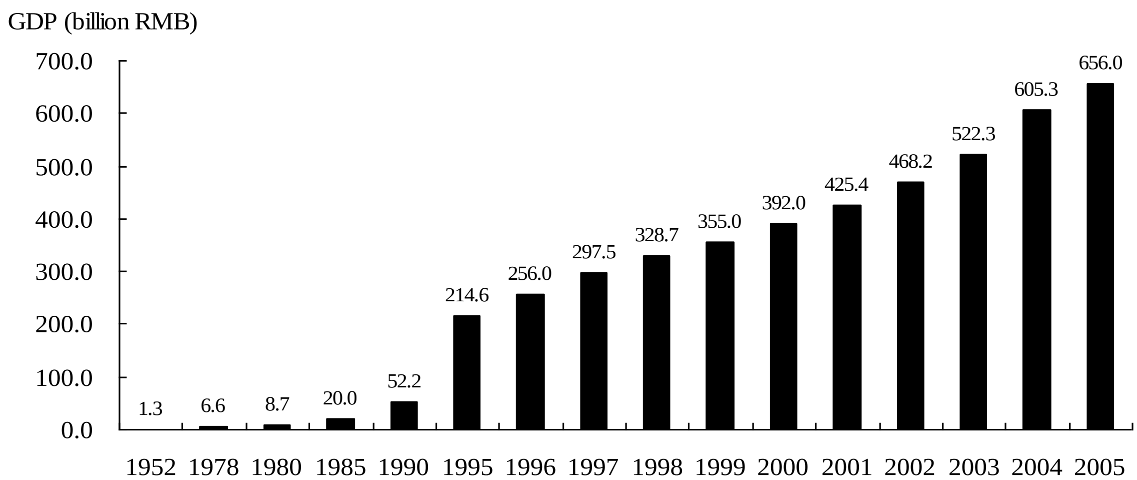


Figure 7-1. The growth in GDP in Fujian Province, derived from data published in the Fujian Statistical Yearbook (2006).

Two research methods were combined in this study: 1) experimental plots to imitate water and soil erosion in the period immediately after construction, and 2) a survey of 90 large-scale construction projects in Fujian undertaken in 1999–2004 in which the impact of construction was assessed by field survey. The assessed impacts included the area of disturbed ground, damage to soil protection facilities, the amount of soil displacement, and the extent of soil erosion. The objective of these two complementary assessments was to examine how and in what scales of infrastructure development affects soil erosion and sedimentation in Fujian, and the mechanisms and measures that can be implemented to reduce this erosion. The results have already been utilized by the Fujian Soil and Water Supervision Agency in perfecting their assessment methods and in the determination of mitigation measures for different construction types.

7.2 METHODS

7.2.1 Experimental assessment of soil erosion

A research site designed to provide quantitative estimates of soil erosion under different types of vegetation was established close to Jianou City (118°57’11’’ E, 27°20’26’’ N), within the Min River Watershed. The annual average temperature at the site is about 18.7 ℃. Annual precipitation is 1664 mm, concentrated between March and September. The soil type in the research area is red soil, derived from Quaternary red clay, and the parent rock is granite (see Higgiti and Rowan, 1996, and Zhu *et al*., 2003, for further information about the nature and characteristics of the ubiquitous red soils). Granite dominates much of the geology of Fujian, particularly in the Min Watershed.

The experiment was designed to simulate water and soil erosion in the period immediately after ground disturbance and to understand how erosion processes change over the course of the first year of exposure. After the first year, most sites are re-vegetated (either deliberately or naturally), complicating further patterns of development, and the study therefore focused on the processes present in the first year of exposure. The experiment consists of a series of rectangular erosion plots (Figure 7–2).

Exposed soil plot without grass (ESWOG)

Exposed soil plot with grass (ESWG)

Natural barren plot (NBP)

Natural vegetation plot (NVP)

Figure 7-2. The four treatments used in the soil erosion experiment in Dongmen, Jianou, Fujian.

Four treatments (Table 7–1) were applied to six observation plots, two having exposed soil with grass, two with exposed soil without grass, and two control plots (one natural barren land and one with natural vegetation). Precipitation, water runoff, and soil runoff were recorded.

Table 7-1. Basic site characteristics of the experimental plots. Further information is provided in the text.

Treatment	Plot description
Natural vegetation plot (NVP)	Nearly 100% cover of native grasses, shrubs and trees, 20 ° slope.
Natural barren plot (NBP)	Barren soil without plant cover, 15 ° slope.
Exposed soil with grass (ESWG)	40 cm depth of soil, grass planted at the time of displacement, 20 ° slope.
Exposed soil without grass (ESWOG)	40 cm depth of soil, no grass, 20 ° slope

Note: Due to the constraints of the experimental situation, the experiment initially focused on comparing ESWG and ESWOG only. However, the authors considered that the additional data from the NVP and NBP plots might provide valuable comparative material, even though they were collected as part of another experiment and have different plot characteristics (much wider and longer than ESWG and ESWOG plots). The data was standardized to tonnes km^2 $year^{-1}$ for sedimentation and mm for runoff depth) in order to minimize the impact of differences in plot size and slope angle.

The details of the four treatments were: 1) For plots with exposed soil without grass (ESWOG) and the exposed soil with planted grass (ESWG), the longer side (projected value) of the plot was 6 m and the short side (parallel to the slope contour) was 5 m. The soil for the four exposed plots was collected from a road construction site near the experiment station. The soil was obtained from a depth of up to 1 m and was piled to a depth of 40 cm on the plot. The grass *Paspalum wetsfeteini* Hackel was planted in the grassed over plots. This is the species recommended by the Fujian Soil and Watershed Supervision Agency to control soil erosion and stabilize slopes at construction sites in Fujian.

The natural barren plot (NBP), simulating barren land, was a former orange orchard that was cleared in April 2000. The plot was 20 m long (projected value) and 5 m wide. During the experimental period, naturally occurring wild grass was removed using a reaphook (i.e., it was cut above ground-level without removing the roots) and the plot was maintained as barren land.

The natural vegetation plot (NVP) was 20 m long by 10 m wide. The vegetation cover consisted of native shrubs and young trees (Chinese fir (*Cunninghamia lanceolata*) and Masson Pine (*Pinus massoniana)*. The average height of the trees was 1.8 m, and crown coverage was almost 100%.

Each plot was edged by concrete boards (2 cm thick, 1 m long and 50 cm wide), embedded 35 cm into the soil. At the bottom of each plot, a gutter 2 m long, 1 m wide and 1 m depth was installed to collect water and sediment (clearly visible in the photo of ESWOG plot in Fig. 6–2).

Construction of the ESWOG and ESWG experimental plots was completed in May 2001 and measurements started in June 2001. The results reported here are for the period June 2001 to May 2002. Rainfall was measured using an automatic rain gauge (SJ-1Rain-Guage) that recorded the duration and intensity of each precipitation event. Runoff was collected in the gutter at the base of each plot. Suspended sediment was collected after each precipitation event, and with three samples (50 ml each) being collected from each gutter. Samples were dried and weighed. Sand and other sediment was collected directly from the bottom of gutter, dried and weighed. Evaporation, temperature, humidity, and soil surface temperature data were collected at a meteorological station adjacent to the experimental station. The data were analyzed in an Excel spreadsheet (Microsoft Office 2003). The relationships between runoff depth, soil erosion and rainfall in the experiment plots were examined.

7.2.2 Survey of large-scale infrastructure project development sites

Between 1999 and 2004, all 90 large-scale infrastructure projects in Fujian were examined by field staff from the Fujian Soil and Water Supervision Agency. At each site, information on the total investment was obtained, and field assessments were made of the area of disturbed ground, damage to soil protection facilities, the amount of soil displacement, and the extent of soil erosion. Any soil protection measures present were noted. The detailed overall plan and specific site plans (including the soil and water conservation plans) were examined. This survey is mandatory for all large construction projects and the data are relatively reliable. The assessment was followed procedures of Guidelines for Monitoring and Measuring the Water and Soil Erosion in Construction Projects (Fujian Department of Watershed Resources Management 2002), and Chinese National Standard of PRC for Water and Soil Erosion Protection Guideline in Construction Project issued by Ministry of Water Resource in 1998 (SL204–1998) and Technical Code of Practice on Water and Soil Conservation Monitoring issued by the Ministry of Water Resources (SL277-2002) in 2002 (the Ministry of Water Resources, 2002). The survey data were provided by the Fujian Soil and Water Supervision Agency.

Large-scale projects are those involving investments of more than US $4 million, and initiated and approved by the central or provincial governments. The 90 projects were classified into six categories: linear construction projects (freeway, railway, gas pipeline, and electricity transmission line), hydropower construction, fuel power construction, mining, flood control, and dyke building.

7.3 RESULTS

7.3.1 Soil erosion in the experimental plots

Comparison among the treatments. The monthly runoff and sediment yields for the four treatments are given in Tables 7–2 and 7–3. Over the one-year study period, the sediment yields in ESWOG, ESWG, NBP and NVP were 441.4 tonnes ha^{-1} year^{-1}, 106.61 tonnes ha^{-1} year^{-1}, 146.91 tonnes ha^{-1} year^{-1}, and 5.92 tonnes ha^{-1} year^{-1}, respectively. The sediment yield from ESWOG was around four times that of ESWG, three times that of NBP, and 7500 times that of NVP. Only the ESWOG plots exceeded the national limit for sediment yield (150 tonnes ha^{-1} year^{-1}; Ministry of Water Resources, 1998). The monthly sediment yield fluctuated according to the amount of precipitation.

Table 7-2. Monthly surface runoff depth in the four treatments.

Month	Monthly precipitation (mm)	Natural vegetation plot (mm)	Natural barren plot (mm)	Exposed soil with grass (mm)	Exposed soil without grass (mm)
June 2001	320	8	80.12	115.33	134.62
July 2001	170	3.4	55.5	65.25	107.21
Aug. 2001	155	2.39	82.02	40.57	122.7
Sept. 2001	10	0	2.67	0.6	0.67
Oct. 2001	40	0.2	7.12	5.33	10.13
Nov. 2001	30	0.12	8.91	3.63	10.17
Dec. 2001	35	0.13	9.34	5.73	5.6
Jan. 2002	125	0.44	41.3	22.27	64.91
Feb. 2001	30	0	2.26	6.53	15.47
Mar. 2002	150	1.84	38.87	23.87	91.13
April 2002	220	3.48	80.29	40.43	133.55
May 2002	115	1.39	35.41	9.92	66.69
Total	1400	21.39	443.81	339.46	762.85

Comparison between the two wet seasons. In southeastern China, the wet season is characterized by two main periods. The Asian Monsoon occurs from March to June, and a series of typhoons occur from July to August (commonly through to September). These two rainfall periods have different characteristics that result in differences in runoff and sediment yield. The precipitation intensity during the typhoon season is much greater than during the Monsoon period. In this research, the wet season (March to August) accounted for 98.2%, 99.9%, 96.4% and 92.9% of the total sediment yield from ESWOG, ESWG, NBP, and NVP plots, respectively. The proportion of runoff from the plots was slightly lower, being 86.0%, 87.0%, 83.9% and 95.8%, respectively (Figure 7–3). During the 2001 typhoon season, 23.2% of the annual rainfall occurred, but 37.8%, 55.1%, 39.6% and 55.3% of the sediment yield from the NVP, NBP, ESWG and ESWOG plots, respectively, occurred. These results are similar to those found by Lu (1989) in eastern Fujian Province.

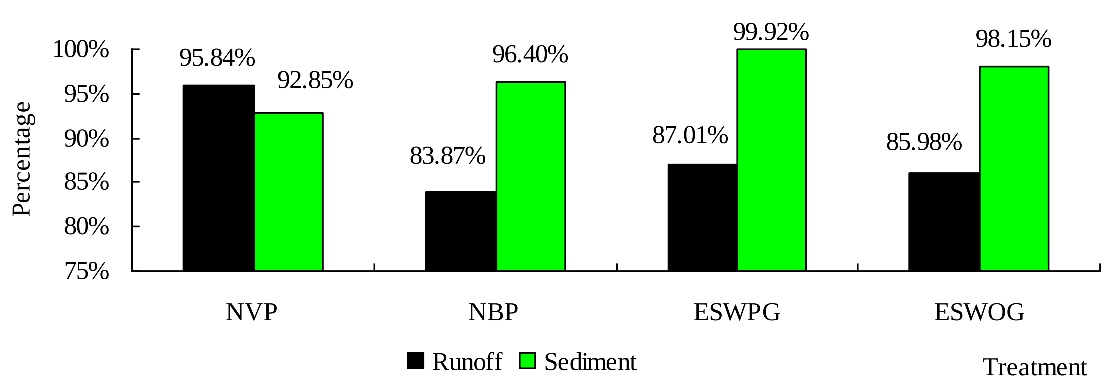


Figure 7-3. The percentage of sediment and runoff during March to August in the experimental period.

Influence of grass seeding. Sediment yields during the first month in plots planted with grass were still high (Table 7–2 and 7–3): 23.4% of the annual precipitation generated 37% of the annual runoff and 60.1% of the annual sediment yield. The sediment yield from the planted plots exceeded that from NBP plots, likely because of the disturbed state of the soil in the ESWG plots. However, the grass cover still reduced sediment yield in comparison to the ESWOG plots. The progressive growth of the grass served to reduce sediment yield, and the sediment yield from the ESWG plots in July was lower than that of either the ESWOG or NBP plots. By August and September, the sediment yield in the grassed plots was further reduced and close to that of the NVP plots (Figure 7–4). 99% of the sediment yield from the ESWG plots occurred over the first three months of the experiment. The plots planted with grass had a sediment yield of 106 t/ha year, 75.8% less than those without grass, and 27.5% less than the NBP plots. The runoff depth from areas planted with grass was 340 mm, 55.5% less than the ESWOG plots and 23.5% less than NBP plots.

Comparison of recently disturbed and long-term bare ground. Disturbed, bare soils (the ESWOG plots) generated 441.4 t/ha sediment yield and a runoff of 762.9 mm annually, values that were 3 times and 1.7 times greater, respectively, than natural barren land (NBP). This much higher yield reflects the easily eroded nature of the disturbed soil, with the soil of the NBP plots being more compacted, having some grass roots binding the soil, and having lower surface roughness.

Table 7-3. Monthly erosion in the four treatments.

Month	Monthly precipitation (mm)	Natural barren plot (tonnes/ha year)	Natural vegetation plot (tonnes/km^2 year)	Exposed soil with grass (tonnes/ha year)	Exposed soil without grass (tonnes/ha year)
June 2001	320	32.14	2.517	64.03	127.1
July 2001	170	23.15	1.35	26.93	86.4
Aug. 2001	155	57.75	0.886	15.31	157.6
Sept. 2001	10	0.001	0.01	0.001	0.015
Oct. 2001	40	1.42	0.085	0.02	2.56
Nov. 2001	30	1.94	0.021	0.013	2.16
Dec. 2001	35	0.12	0.048	0.017	0.42
Jan. 2002	125	0.04	0.044	0.027	0.63
Feb. 2001	30	1.77	0.215	0.012	2.38
Mar. 2002	150	6.28	0.212	0.074	8.89
Apr. 2002	220	20.49	0.515	0.17	44.4
May 2002	115	1.81	0.016	0.003	8.81
Total	1400	146.9	5.92	106.6	441.4

The relationship between runoff, sedimentation and precipitation. The factors influencing soil losses in the plots are complex. The exponential, power and linear function regression were examined. In all treatments, a significant linear relationship was found between runoff depth and rainfall (Table 7–4). A number of site-specific factors have a direct bearing on the occurrence and volume of runoff, such as rainfall characteristics (intensity, duration and distribution), soil type, vegetation, slope and catchment size (FAO, 1965). The linear relationship may not be supported in other cases since runoff may increase exponentially as rainfall increase and the soil becomes saturated. Hadda and Kukal (1991), for example, reported that a power function performed better than an exponential or linear function in estimating runoff from daily rainfall. The linear relationship found in this study may be related to the conditions during the year of the study, as it was relatively dry (see below).

The relationship between sediment yield and rainfall was more variable across the treatments (Table 7–5). The linear and power relationships were significant ($p<0.05$) for the NVP plots only, although the R^2 values were low. In the remaining three treatments, only the power relationships between soil erosion and rainfall were significant, and the R^2 values were again quite low.

We compared the finding with the predictions of the USLE (Hudson, 1981), but it is difficult to explain the results (exposed soil with and without grass). The conditions of this research site are beyond the application of the equation. The model is based on US data from agricultural slope angles in the range from 0 to 5^o (Barker, 1995), specifically croplands experiencing Hortonian overland flow. The slopes at the research site were 15^o and 20^o, well outside the range used with the USLE. Also, the USLE has been shown not to apply to tropical soils and climate conditions (Odermerho, 1986); Fujian's subtropical soils and climate may be equally inapplicable, although a modified USLE was used for sub-tropical conditions in Africa (Hudson, 1961). Several research studies done at the Beijing Transportation University, Chongqing University and Zhengzhou School for Water Resources Management (Ye et al., 2001) have shown that the USLE is unsuitable for the prediction of soil erosion at construction sites in China, as it is designed to predict long term annual average soil erosion over relatively constant areas, such as natural slopes, agricultural land and forest land. At construction sites, the soil structure is highly disturbed and altered.

Table 7-4. Relationship between runoff depth and rainfall in the experimental plots.

Treatment	Linear regression model	P-value	R^2
Natural vegetation plot	Y=0.027x-0.347	<0.0001	0.831
Natural Barren plot	Y=0.341x-0.235	<0.0001	0.741
Exposed soil with planted grass	Y=0.0361x-1.566	<0.0001	0.612
Exposed soil without planting grass	Y=0.4859x+1.439	<0.0001	0.537

Table 7-5. Relationship between soil erosion and rainfall in the experimental plots.

Treatment	Regression model	p-value	R^2
Natural vegetation plot	$Y=0.33+0.04x$	0.006	0.229
	$Y=0.13x^{0.6}$	0.025	0.156
Natural barren plot	$Y=1817.86+47.76$	0.147	0.047
	$Y=2.84\ x^{1.7}$	0.000	0.279
Exposed soil with planted grass	$Y=649+63.25x$	0.220	0.036
	$Y=0.39x^{1.6}$	0.003	0.187
Exposed soil without planting grass	$Y=4838.87+165.64x$	0.185	0.040
	$Y=1.05x^{2.14}$	0.000	0.292

7.3.2 Survey of large-scale project development sites

Following procedures established by the Fujian Soil and Water Supervision Agency based on the national standard issued of the Ministry of Water Resources of China in 2002 and the guideline by Fujian Department of Watershed Resources Management in 2002, each project was examined for investment, surface disturbance, damage to the original soil/water protection infrastructure, excavation of soil and rock and replacement of soil and rock. The biggest total investment in large-scale projects was in linear constructions (e.g., freeways, highways, railways, oil and gas pipelines, and electric and communication lines). The average investment per project was US$ 200.2 million. The biggest investments in individual projects were in thermal power plants, with an average cost per plant of US$ 554.79 million. Construction projects related to hydroelectric power, dyke building, flood control and mining were relatively small, with investments ranging from US$ 15 million to US$ 55 million. The total area identified as being affected by soil erosion caused by all forms of infrastructure construction (including small- and medium-scale projects, which were not included in this assessment) was about 39,874 ha, 0.33% of the land area of Fujian province. However, the 90 large-scale construction projects accounted for 55.8% of the surface disturbance, a total area of 22,251 ha (excluded 21,099 ha of water surface). The following analysis focuses on the impacts of the 90 large-scale construction projects. Estimates of the impacted area and volumes of soil involved are presented in Table 7–6.

Table 7-6. The impact of construction projects on the environment of Fujian

Project	Number of projects	Total investment (million US$)	Surface disturbance (ha)	Damage to original protection facility (ha)	Soil and rock excavation (1000 m^3)	Replacement of soil and rock (1000 m^3)	Estimated soil erosion (1000 ton)*
Hydro power	47	2497.6	23,855	2947	27,403	20,210	6496
Thermal power	8	4188.3	893	860	12,585	3203	2131
Linear Construction	16	11118.6	14,213	11,169	276,393	86,230	9539
Mining	8	147.1	3660	872	252,036	217,274	15,889
Dyke building	3	100.8	116	84.7	8614	203	36.1
Flood control	8	154.6	593	489	9026	1193	915.6
Total	90	18207	43,328	16,422	586,058	328,313	35,006

(*Soil erosion was estimated by using GPS and soil erosion sticks**)**

Surface disturbance and soil erosion associated with different types of development.

The extent of disturbance associated with projects was variable (Table 7–6). Mining had the greatest impact on the surface, followed by hydroelectric station construction, flood control infrastructure, linear construction, and dyke building. The least damaging were thermal power projects (Figure 7–4).

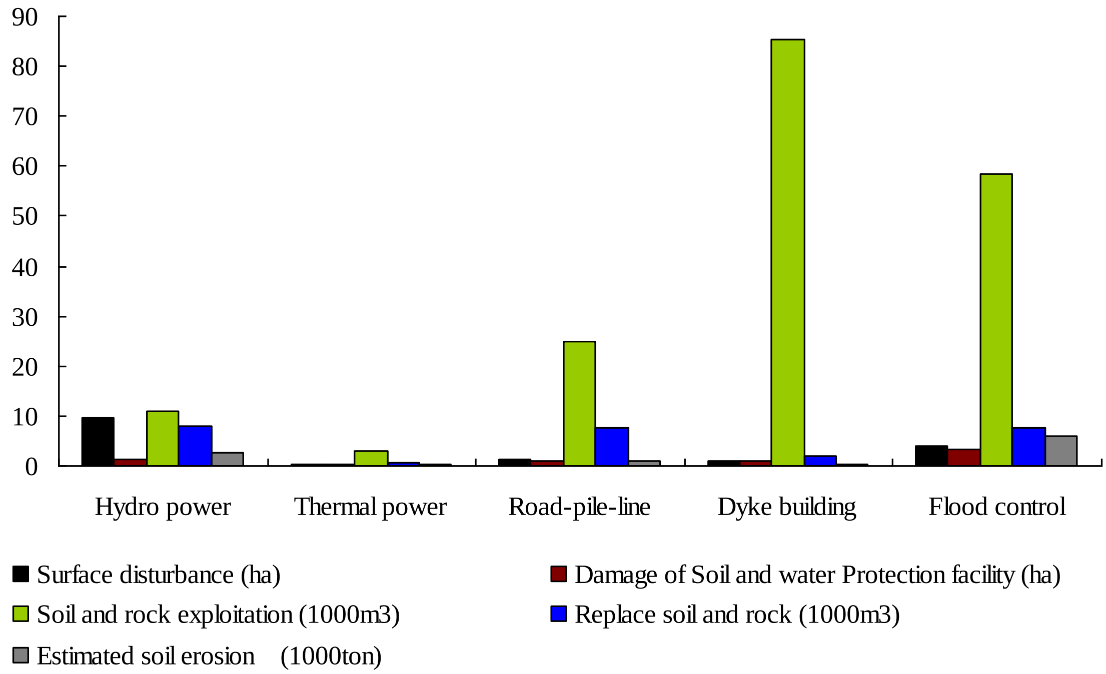


Figure 7-4. Soil erosion in different types of construction portrayed as a function of unit investment.

Comparison between development projects. The large-scale projects in Fujian between 1999 and 2004 involved the construction of 1118 km of freeway and 678 km of railway. For each kilometre of construction, the area of land disturbed by freeway construction was almost double that of railways. The soil erosion associated with freeway construction was about 1.7 times higher than for railways (Table 7–7). When the erosion associated with different types of energy generation was compared, the erosion associated with the construction of hydropower plants was almost ten times higher than that associated with thermal power plants (Table 7–8).

Table 7-7. Comparison of the impacts of freeway and railway construction.

Project	Investment (US$ million/ km)	Surface disturbance (ha/km)	Damage of Soil and water Protection facility (ha/km)	Soil and rock exploitation ($1000m^3$/km)	Replace soil and rock ($1000m^3$/km)	Estimated soil erosion (1000 tonnes/km)
Freeway	5.42	9.53	8.18	184.4	56.4	5.9
Railway	6.52	4.95	2.86	100.6	32.8	3.47

Table 7-8. Comparison of the soil erosion associated with the construction of hydro and thermal power stations.

Project	Investment (US$/kw)	Surface disturbance (m^2/kw)	Damage of Soil and water protection facility (m^2/kw)	Soil and rock exploitation (m^3/kw)	Replace soil and rock (m^3/kw)	Estimated soil erosion (tonnes/kw)
Hydropower	88.1	8.41	1.04	0.97	0.71	0.23
Thermal power	50.5	0.11	0.11	0.15	0.04	0.03

Investments in soil and water protection The large-scale construction projects were all well-funded, mainly by provincial or central governments. The government's requirements for soil and water protection were strict (Table 7–9), and the average investment in soil protection was around 0.47% of the total investment. The investment was used for engineering measures (physical construction) and bioremediation, such as planting trees and grass. Of the different types of project, mining projects invested the highest proportion (almost 10%) of the total cost in soil and water conservation.

Table 7-9. Investment in soil and water protection in large-scale projects conducted in Fujian, China, between 1999 and 2004.

Project	Total investment (million US$)	Investment in soil and water protection						Total disturbed area (ha)	Protected		Planted	
		Total (million US$)	%	Engineering measures		Bioremediation measures						
				Sub-total	%	Sub-total	%		Area	%	Area	%
Hydro power	2497.6	19.88	0.8	11.06	55.6	3.06	15.4	2948	2915	98.9	1364	46.3
Thermal power	4188.3	6.52	0.2	1.74	26.7	2.06	31.6	830	857	96	630	70.6
Linear construction	11,118.6	41.9	0.4	11.74	28.0	6.23	14.9	14,213	12166	85.6	4050	28.5
Mining	147.1	14.28	9.7	8.58	60.1	3.49	24.4	3660	1156	31.6	509	13.9
Dyke building	100.8	1.03	1.0	0.58	56.6	0.18	17.6	116	84.7	73	55.9	48.2
Flood control	154.6	3.20	2.1	1.93	60.2	0.51	15.8	593	556	93.9	253	42.7
Total	18207	86.81	0.47	35.63	41.0	15.53	17.9	22,358	17,735	79.1	6862	30.6

7.3.3 Processes of soil erosion at the construction sites

An understanding of the processes of soil erosion at construction sites is a first step in soil and water conservation. In this survey, five major processes were identified at the construction sites: sheet erosion, rill erosion, gully erosion, landslides and debris torrents (debris flows). Sheet erosion (including splash erosion) was the most common pattern of soil erosion and was ubiquitous throughout the construction sites. Rill erosion (with a depth of between 20 and 100 cm and lengths of up to 10 m) was observed in short-term projects. In longer-term projects (such as mining and freeway projects), the rills generally developed into gully erosion (defined as channels over 1 m in width and depth, and over 10 m in length).

7.4 DISCUSSION

The results from a simulation experiment that compared soil erosion across different land covers for a period of one year following exposure showed that the disturbed plots without grass generated 441.4 t/ha and a runoff of 762.9 mm annually, values that are 3 times and 1.7 times greater, respectively, than naturally barren plots. Disturbed plots with grass cover had a sediment yield of 106 t/ha year, 75.8% less than when there was no grass, and 27.5% less than the naturally barren plots. The runoff from areas planted with grass was 339.5mm, 55.5% less than plots without grass and 23.5% less than naturally barren plots. Two periods were particularly important: March to June and July to September, with 42.9% and 55.3%, respectively, of the annual soil erosion. This corresponds with the annual wet season associated with the Asian monsoon and summer typhoons. Bearing in mind that 50% of the exposed soil at construction sites had not been re-vegetated, timing construction properly and the immediate reseeding of exposed soils could reduce soil erosion significantly. These results could be used to aid policy makers in developing sound management practices to control soil and water loss in the subtropical red soil area of southeast China.

While there appears to be a relatively straightforward relationship between runoff and rainfall amount, the relationship between rainfall and soil erosion is complicated, depending on various factors including land use, human disturbance, rainfall intensity, and vegetation. Huang *et al*. (2000) established a set of experiments throughout Fujian to quantify the major factors influencing the rates of soil erosion. The relationships between soil erosion intensity and a series of variables – vegetation cover, vegetation structure, land use, slope, lithology, engineering measures, organic matter, soil texture, soil dispersion and rainfall erodibility index – were analyzed. The major variables influencing soil erosion were the vegetation cover, engineering measures, rainfall erodibility index, slope, organic matter content of the soil, land use, and lithology. The same conclusion was reached by Ownens et al. (2000) at two small construction sites in Dane County, Wisconsin. Other research in China supports the results obtained here. Lu (1989) found that in eastern Fujian, precipitation amount alone could explain the quantity of soil erosion. Wang *et al*. (1998) have argued that on the Loess Plateau, soil erosion is triggered by rainfall intensities of 40 mm in 24 hr. Rainfall intensities in excess of 60 mm in 24 hrs can cause quite severe erosion, but the statistical relationships were less clear than for 24 hrs amounts between 40 and 60 mm. Li and Taishim (1990), conducting their research in an area of black soils, found that soil erosion increased with rainfall amount, although the strength of the relationship declined exponentially.

A limitation of the experiment is that the observation period lasted only one year. Long-term monitoring is needed to detect and fully understand the differences in the treatment responses. Moreover, 2001–2002 was relatively dry, with a total precipitation of 1471 mm (the annual average is 1664 mm). Precipitation in September, February and May was particularly low (Figure 7–5). This means that the results from the experimental plots presented here may be atypical, and the experiment would benefit from both replication in a number of different years and extension to more than a single year of monitoring.

Our results from the large-scale project survey confirm that soil erosion from construction sites is a significant source of sediment and other suspended solids. The construction has altered landforms, vegetation and waterways, and has led to water and soil erosion and land degradation. The examination of the 90 large-scale infrastructure projects found that there were significant differences in the soil erosion associated with different construction projects. As continuously development of its economy, infrastructure construction in Fujian seems to be increasing dramatically in the near future. Decision-makers need to consider these results and decide whether the environmental costs associated with for example the construction of a freeway can be justified when the construction costs associated with a railway are so much less. Similarly, whereas most environmentalists in China would prefer a hydro-electric power station over a thermal power station (depending on the local situation), the much greater erosion associated with hydroelectric constructions (such as dam, channel and water system development) needs to be taken into account in environmental cost–benefit analysis. Moreover, the lesson from the simulation experiment showed that timing of a construction and whether or not the immediate reseeding of exposed soils is greatly affected on soil erosion. Appropriate timing for construction and reseeding after soil exposure should be two key criteria for a soil and water conservation agency to consent or monitor a construction project in the subtropical red soil area of southeast China.

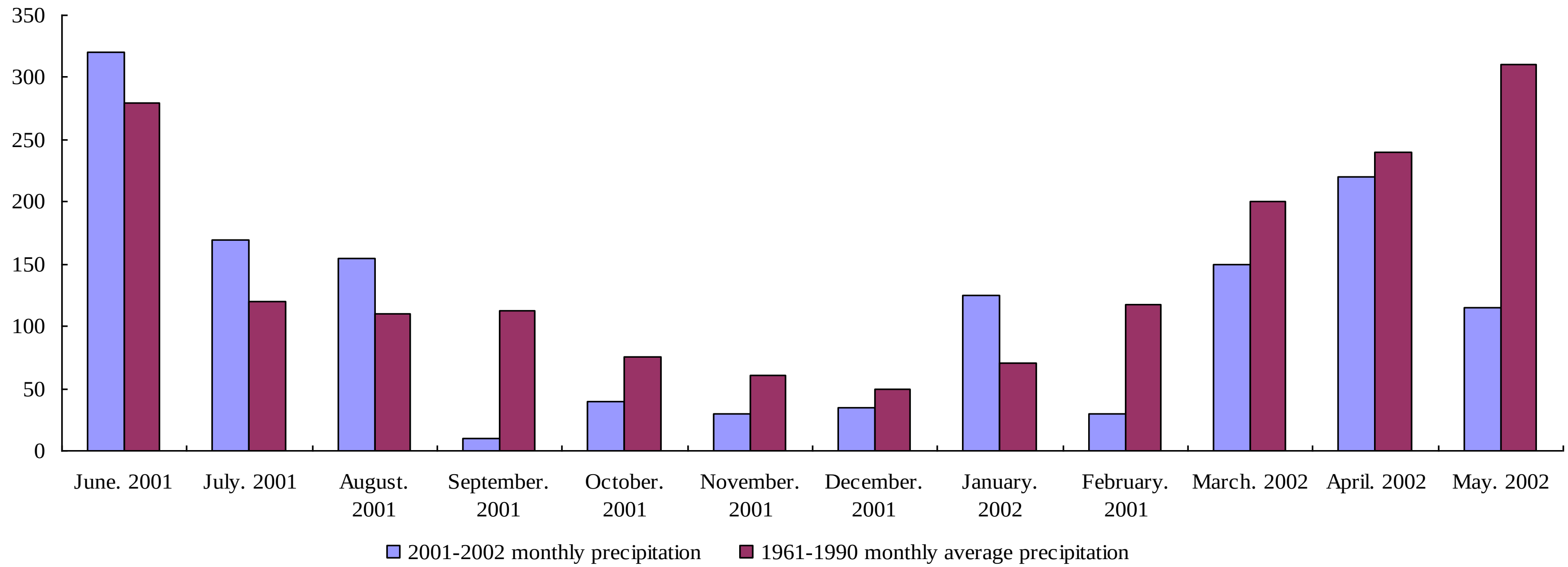


Figure 7-5. Monthly precipitation during 2001–2002, and monthly average during 1961–1990.

7.5 CONCLUSIONS

Soil erosion has become a major issue in China because of the rapidity of economic development and land-use change. As has been found elsewhere (Pitt et al. 2007), our research has indicated that infrastructure construction is a major contributor to soil erosion and land degradation in the sub-tropical red soil region of southeastern China. The poor management of exposed soil and rock at construction sites has accelerated soil erosion and river sedimentation, particularly as spoil is often dumped directly into rivers. The result has been increased sedimentation in rivers and an associated increase in the frequency and severity of floods. The simulation of four common situations in the region reveals that soil erosion could be dramatically reduced if construction activities avoided exposing bare soil during the summer wet season, especially the typhoon season from July to September. In addition, if physical engineering measures were to be applied in the first three months of the wet season, erosion could be reduced. The more widespread use of grass-seeding could greatly reduce the extent of erosion at many sites.

7.6 REFERENCES

Barker, D.H. 1995. The way ahead- continuing and future development in vegetative slope engineering or ecoengineering, *Proceedings of International Conference on Vegetation and Slope- Stabilisation, protection and Ecology,* Institution of Civil Engineers. Oxford and Landon.

Barrett, M.E., Malina, J.F. Jr., Charbeneau, R.J. and Ward, G.H. 1995a. *Water quality and quantity impacts of highway construction and operation: summary and conclusions*. Center for Research in Water Resources Technical Report 266, University of Texas, Austin, TX.

Barrett, M.E., Kearney, J.E., McCoy, T.G., Malina, J.F. Jr., Charbeneau, R.J. and Ward, G.H. 1995b. *An evaluation of the performance of temporary sediment controls*. Center for Research in Water Resources Technical Report 261, University of Texas, Austin, TX.

Barrett, M.E., Malina, J.F. Jr. and Charbeneau, R.J. 1998. An evaluation of geotextiles for temporary sediment control. *Water Environment Research* 70: 283–290.

Booth, D.B. 1990. Stream channel incision following drainage basin urbanization. *Water Resources Bulletin* 26: 407–417.

Chen, Q.X. 2000. Situation of soil and water conservation based eco-environment and sustainable development of society and economy. *Bulletin of Soil and Water Conservation* 20(3): 1–5.

Critchley, W. and Siegert, K. 1991. *Water Harvesting*. FAO - Rome, 1991. http://www.fao.org/docrep/U3160E/u3160e05.htm#3.5 rainfall runoff relationship

Edwards, F.G. and Burian, S.J. Construction site erosion and sediment control. 2002. Course material – Presentation. Department of Civil Engineering. University of Arkansas.

FAO 1965. Soil erosion by water, some measures for its control on cultivated lands. FAO Agricultural Development Paper: p81.

Fujian Department of Watershed Resources Management 2002. *Guidelines for monitoring and measuring the water and soil erosion in construction projects*. Fujian Department of Watershed Resources Management, Fuzhou.

Fujian Provincial Bureau of Statistics 2006. Fujian Statistical Yearbook. China Statistical Press: Beijing.

Hadda, M.S. and Kulal, S.S. 1991. Relationships among rainfall, runoff and soil loss for the design of soil and watershed conservation works in submontane Punjab. *Soil use and Management* 7(1): 45-47.

Harbor, J. 1999. Engineering geomorphology at the cutting edge of land disturbance: Erosion and sediment control on construction sites. *Geomorphology* 31: 247–263.

Higgiti, D.L. and Rowan, J.S. 1996. Erosion assessment and administration in subtropical China: a case study from Fujian Province. *Land Degradation and Development* 7: 1–10.

Hu S.L. and Chen, Z, Q. 2006. Changes of the main land use types in Minjiang watershed and their effects. *Fujian Geography 20 (2):15-18,9.*

Huang, Y.H., Lin, J.L., Cai, Z.F., Chen, M.H. and Zhou, F.J. 2000. Major influential factors of soil erosion in Fujian Province. *Journal of Soil and Water Conservation* 14(2): 36–40.

Hudson, N.W. 1961. An introduction to the mechanics of soil erosion under conditions of subtropical rainfall. *Rhodesia Science Association, Proceedings* 49:14–25.

Hudson, N. W. 1981. *Soil Conservation.* 2nd Edition, Batsford, London, England.

Jiao, Q.R. 1998. *Soil and water protection in construction sites*. China Legal Press: Beijing.

Kaufman, M.M. 2000. Erosion control at construction sites: Science–policy gap. *Environmental Management* 26(1): 89–97.

Ministry of Water Resources 1998. *National Standard of PRC for water and soil erosion protection guideline in construction project*. Department of Soil and Water Conservation, Ministry of Water Resource. SL204–1998.

Ministry of Water Resources. 2002. *Technical Code of Practice on Water and Soil Conservation Monitoring.* Ministry of Water Resources. SL277-2002.

Li, C.B. and Taishim, H.Y. 1990. Study on Impact of rainfall characteristics on soil erosion. *Journal of Soil and Water Conservation* 4(3): 63–67.

Lu, C.D. 1989. Soil erosion and control in the granite area in the eastern Fujian Province. *Journal of Fujian Agriculture College* 17(4): 504–509.

Ownes, D.W., Jopke, P., Hall, D.W., Balousek, J. and Roa, A. 2000. Soil erosion from two small construction sited, Dane County, Wisconsin. U.S. Geological Survey: 1-4.

Odermerho, F.O. 1986. Variation in erosion-slop relationship on cut slopes along a tropical highway. *Singapore Journal of Tropical Geography* 7 (2): 98-107

Pitt R. E., Clark, S., and Lake, D.W. 2007. *Construction Site Erosion and Sediment Controls: Planning, Design and Performance*. DEStech Publication, Inc. USA. pp 380.

Price, D.J.and Brige, J.W. 2005. Effectiveness of stream restoration following highway reconstruction projects on two freshwater streams in Kentucky. *Ecological Engineering* 25: 73–84.

Wang, L.X. 2003. *Soil and water protection*. China Forestry Publish House: Beijing.

Wang,Y., Li, L.F., Wang, X.J.,Yu, X.B., and Wang, Y.H. 2008. *Taking stock of integrated river basin management.* Science Press: Beijing.

Wang, Z.L., Shou, M.N. and Wang, Q.R. 1998. The impact of rainfall on soil erosion in Loess Plateau. *Journal of Northwest Agriculture University* 26(4): 101–105.

Willett, G. 1980. Urban Erosion, in National Conference on Urban Erosion and Sediment Control: Institutions and Technology. EPA 905/9-80-002. U.S. Environmental Protection Agency.

Ye. C.L., Xu, Z.Y., Dong, L. K. and Zhou, H. 2001. The problem in using USLE to prodict soil erosion in a construction site. *China Soil Protection*. 12: 29-33.

Zhu, L.Q., Xu, L.M. and Wang, A.P. 2003. Research on physical and chemical characteristics of red soil in Fujian Province Mountainous Area. *Journal of Henan University (Natural Science)* 33(2): 54–66.

8 PUBLIC AWARENESS AND PERCEPTIONS OF WATERSHED MANAGEMENT IN THE MIN RIVER AREA, FUJIAN, CHINA[10]

8.1 INTRODUCTION

There is a very long tradition of stakeholder involvement in water management in European countries (e.g. Orr et al., 2007; Enserink, 2007). In the Netherlands, for example, the founding of the Polder Boards in the 10th Century recognized the importance of the involvement of local landowner organizations; while in Spain, water irrigation association as a form of management by users can be traced back to Roman and Arab times (Patel and Stel, 2004). However, canvassing public opinion in a country such as China is difficult, especially at its current stage of social, economic and political transition. There are a number of reasons for this. The flow of information is strictly controlled and rarely shared (Lum, 2006; Report to Congress, 2004), so there is a lack of awareness amongst the public of many of the biggest issues faced by the country (e.g., He and Chen, 2001; Watts, 2003). Amongst some, there is still fear of political persecution, which may or may not be justified. Furthermore, some issues are related to particular individual, institutional or regional interests, and any change may be resisted. Despite these difficulties, public participation, community involvement, the contribution of local wisdom and knowledge, and the cooperation of multiple stakeholders across temporal-spatial and political boundaries are vitally important to the successful development and implementation of watershed management planning (e.g., Newson, 1992; Naiman and Bilby, 1998; Wang, 1999; Jones *et al*., 2002; Davenport, 2003; Debarry, 2004; Palmer *et al*., 2004).

The Min River, one of largest ten watersheds in China, has played and continues to play an important role in the social, environmental and economic development of Fujian Province. It accounts for over half of the Province's total agricultural production, two-thirds of the commercial logging, and three-fifths of the drinking water. GDP is around US$ 26.5 billion, representing 35% of provincial GDP and 34.6% of industrial production (Fujian Provincial Bureau of Statistics, 2005). The Min River has undergone dramatic change in the last three decades as the government has encouraged rapid industrialization along the river (Fujian Chorography Compilation Committee, 2002). The rapid population growth and economic development in the watershed have caused serious local and regional environmental problems. The upper reach's mills release pollutants into the river; these pollutants are carried downstream to local communities competing for water to irrigate their farms and villages (Chen, 2000; Fujian Environmental Protection Agency, 2005). Farmers, seeking better city services (Huang and Zhang 2008, Wang 2008), have moved closer to the river, fuelling massive residential construction projects that put greater pressure on the area's natural resources. Now, almost one-third of Fujian's population of approximately 12 million people inhabits the watershed. The government has built transportation grids to accommodate this growth, but its focus on economic development at the expense of environmental and social benefits (You, 2006; Chen *et*

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al., 2006) has resulted in severe over-crowding, air, water and soil pollution, water resource depletion, soil loss, drought and flooding.

In recent years, misuse of the watershed, in the form of massive infrastructure construction without associated soil and water protection (Wang *et al*., 2008c), over-cutting of the forest, and overexploitation of water resources for fish and animal husbandry along the Min River, have led to increased runoff, soil erosion, stream sedimentation and flooding. Since 1997, Fujian has suffered massive social, economic and environmental damage as a result of floods and droughts. The flooding in 1998 alone cost the province US$ 1.2 billion, including both direct and indirect damage (Fujian Chorography Compilation Committee, 2002). State agencies manage mainly at the county level, with little knowledge of how their actions may influence the watershed downstream (Chen *et al*., 2006). The Fujian Provincial Government has passed the Min River Protection Act and the Ten-Year Management Plan; these aim to mitigate the environmental and social impacts of industrialization on the River. However, both lack rigour, and fail to offer details of how a more sustainable balance between the environmental, social and economic demands on the river watershed will be achieved. The results presented here are part of an on-going research project into the sustainable development of the Min River Watershed launched by Fujian Provincial Government and aided by the Central Government of China and a number of international funding organizations.

Questionnaire surveys are a key technique in social inquiry (e.g., Yin, 2003; Bryman, 2004; Babbie, 2004). The method is widely used in marketing research and policy assessment. However, there have been few attempts to use questionnaire-based research in the study of watersheds or in large-scale ecological programs, perhaps reflecting the divide in the methodologies employed by social and natural scientists. In forestry, Elsasser (2007) has used a questionnaire approach to analyze views about central forest policy in Germany, and Tindall (2003) used questionnaire and interview approaches to analyze the relationship between abstract forest values and opinions about more specific forest practices. Such research has generally focused on particular issues, rather than examining social, economic and environmental issues holistically. In this study, a questionnaire (see Appendix I) was used to examine public awareness and expectations about watershed issues, and to identify public views about environmental issues and their solutions. The study was conducted throughout the watershed, with a broad cross-section of the public being included.

8.2 RESEARCH METHODOLOGY

8.2.1 Research area

The Min River is located in south-eastern China, between 116° 30’ and 119° 30’ E and 25° 20’ and 28° 25’ N (Figure 1–1). It is the biggest (in terms of both length and annual discharge) river in Fujian Province and one of the ten biggest rivers in China. The headwaters of the Min River are situated at an elevation of about 2115 m in the Wuyi Mountains in the north-western section of Fujian. Flowing generally east through the cities of Sanming, Nanping, and Fuzhou, the catchment covers an area of 60,992 km^2 and the river travels 2872 km to reach the sea. The main river (the section located downstream of the confluence of the main tributaries at Nanping) has a length of 559 km.

The watershed covers 37 counties (cities and districts) in Fujian province. The watershed is characterized by a large area of headwater catchments and smaller, deeply incised middle and lower reaches (Figure 1–1the map of the watershed and Table 8–1).

Table 8-1. Min River Watershed jurisdiction.

Reach	County
Upper reach	SanYuan, Meilie, Yongan, Mingxi, Qingliu, Ninghua, Shaxian, Jiangle, Taining, Jianning, Yanping, Shaowu, Wuyishan, Jian'ou, Jianyang, Shunchang, Pucheng, Guangze, Songxi, Zhenghe, Liancheng, Yongchun
Middle reach	Gutian, Youxi, Datian, Pingnan
Lower reach	Gulou, Cangshan, Taijiang, Mawei, Jin'an, Changle, Minhou, Lianjiang, Minqing, Yongtai, Dehua

More than 12 million people live in the watershed, accounting for 34.5% of the total population of the province. 65% of the residents are farmers or work in agriculture-related activities, such as tree planting and the harvesting of timber and non-timber forest products, horticulture, tea plantations, fish and animal husbandry, and mushroom farms. 35% of people are employed by manufacturing industries. 52% of the population is male (Table 8–2).

8.2.2 Economic characteristics of the watershed

The total GDP for the watershed is US$ 26.5 billion, or about one third that of Fujian Province (Fujian Provincial Bureau of Statistics, 2005). This represents a 64% increase between 2000 and 2004, and reflects increases in the secondary and tertiary industries over the same period of 78.8% and 64.6%, respectively (Table 8–3). At the same time, there has been a decrease in the proportion of GDP accounted for by primary industries, which have increased by only 32.5%. The watershed is used for generating hydroelectricity for urban and industrial use, irrigation, flood control, navigation, recreation, fishing and wildlife conservation. There are 29 large-scale hydropower stations in the watershed, and a major facility is currently being constructed at ShuiKou, Minqing County, that will have the capacity to generate 1.4 million kilowatts annually. This will be the biggest hydro-electric power plant in eastern China.

Table 8-2. Total population in the Min River Watershed at the end of 2004. Units are in 10,000. (Adapted from Fujian Provincial Bureau of Statistics 2005).

Area	Population		By location				By sex			
	Total	%	Rural Population	%	Urban population	%	Male	%	Female	%
Upper reach	703	58.0	487	69.3	216	30.7	366	52.0	337	48.0
Middle reach	84.4	6.79	64.6	76.5	19.9	23.5	44.7	52.9	39.8	47.1
Lower reach	424	35.0	242	57.0	183	43.0	220	51.9	204	48.1
Total	1212	100	794	65.5	418	34.5	631	52.1	581	47.9

Table 8-3. Gross Domestic Product at the end of 2004. Units are in million Yuan. (Adapted from Fujian Provincial Bureau of Statistics 2005).

Reach	Gross Domestic Product	Primary Industry	Secondary Industry			Tertiary Industry	Per Capita GDP(Yuan)
			Subtotal	Industry	Construction		
Upper reach	879	193	362	285	77.6	324	304,481
Middle reach	79.2	28.3	26.5	19.0	7.5	24.5	19,275
Lower reach	1161	100	582	475	107	478	123,806
Total	2119	322	971	779	192	827	447,561

8.2.3 Survey method and data analysis

The questionnaire focussed on three main areas of interest: the level of public awareness about the importance of sustainable watershed management, the main concerns about watershed management, and the principal reasons for watershed deterioration and how these might best be managed. The questionnaire was divided into eight sections, described in Table 8–4.

8.2.4 Survey methods and target research population

The questionnaire was developed in English and then translated into Chinese. Before mailing out the survey, it was pre-tested with a range of stakeholders from Fuzhou National Park. 20 participants were interviewed after completing the draft questionnaire. The questionnaire was modified based on this feedback. Approximately 90 minutes were needed to complete the questionnaire. 1200 questionnaires were distributed to addresses selected from the Fujian Residences Registration Offices, using random sampling. The letter was addressed by name to the main person registered in each household. In order to have consistent criteria to answer the questionnaires, guidelines for the interpretation of the questionnaire were developed and a team of 15 people from Fujian Department of Forestry, Fujian Agriculture and Forestry University, were trained and were available to facilitate and help people complete the questionnaires, if needed. Such help included clarifying any questions that were unclear, and help in filling out the form in cases where the respondent was illiterate. Team members also contacted and in many cases visited any individual who had not responded by a specified date. This approach differs markedly from the mail or internet surveys commonly administered in western academic studies, which tend to have relatively low response rates. The personal follow-up by the survey team with each of the respondents ensured a relatively high response rate of 87.5% (see below). All respondents were given the option of not responding, but many found the questionnaire a novel and intriguing opportunity to express their views about the governance of the watershed in a way that guaranteed their anonymity.

Table 8-4. Structure and components of the questionnaire.

Section	Questions	Purpose
Personal information	15 main questions (closed)	Background information on the participant, level of understanding of the watershed concept, general attitudes towards watersheds and watershed management.
Present issues	12 main questions (closed)	Assessment of the level of understanding of watershed development and current issues.
Watershed administration	11 main questions (closed)	Assessment of the level of understanding of the importance of the watershed and watershed management strategies
Forest management	3 questions (closed)	The impact of forest management on the watershed and the importance of multiple values in social, economic and environmental protection.
Government role	14 questions (closed)	Satisfaction with watershed policies, and with decision making, planning, and enforcement.
Willingness to pay	8 questions (closed)	Identification of the willingness to pay for watershed management.
Public awareness and participation	10 questions (semi-closed)	Assessment of public awareness and willingness to participate in watershed protection.
Suggestions	2 questions (semi-closed)	Assessment of personal opinions on how to manage watershed sustainability and personal actions needed to achieve the goals.
Total	75 questions	

8.2.5 Response rate, data treatment and analysis

A total of 1050 questionnaires were returned, representing a response rate of 87.5%. However, some questionnaires were very incomplete, and only 849 questionnaires were considered sufficiently complete to be used in the analysis. Data were tabulated and managed in an Excel spreadsheet. SPSS 15.0 (SPSS Inc. 2006) was used for the data analysis.

Responses were primarily examined by descriptive data analysis. Pearson's χ^2 test (Anderson *et al*., 2002) was used to test the goodness of fit and independence of observations (e.g., if an observed frequency distribution differed from a theoretical distribution, or whether or not paired observations, expressed in a contingency table, were independent of each other). The procedure involved calculating the χ^2 statistic by finding the difference between each observed and theoretical frequency for each possible outcome, and then, squaring them and dividing each by the theoretical frequency, and taking the sum of the results:

$$X^2 = \sum_{i=1}^{n} \frac{(Fa - Fe)^2}{Fe}$$

where: Fa is an observed frequency;
Fe is an expected (theoretical) frequency, asserted by the null hypothesis; and

N is the number of each event.

Finally, a p-value was calculated by comparing the value of the statistic to a χ^2 distribution. A probability of 0.05 was used to reject or accept the null hypothesis.

8.3 RESULTS

8.3.1 Analysis of responses

Responses were obtained from all counties, with between 19 and 24 questionnaires returned from each county. The percentages of the questionnaires returned from counties in the upper, medium and lower reaches of the watershed reflected the populations in each area (Table 8–5). The responses were biased towards male respondents (64.2 % of the returns), as the primary person registered as being responsible for a household tends to be male.

Table 8-5. Response distribution by reach.

Reach	Counties	number of responses	Average per county	number of total response	Reach population as % of watershed population
Upper	22	547	25	64%	58.0
Middle	4	76	19	9%	6.79
Lower	11	226	21	27%	35.0
Total	37	849	24	100%	100

In Table 8–6, the nature of the respondents is broken down by age group, marital status and income range. Most of the respondents were between 18 and 59 years in age, with the majority (75.8 %) being between 30 and 49, and 79.6% were married with a child. Most (78.8%) had lived in the watershed for more than 20 years. The highest occupational category was ‘other’, a group that included people from NGOs, community workers, educators and so on. Government employees made up 31.3% of the sample. Most respondents indicated that their work was related to the watershed: 36% believed that it was directly related, 40.6% that it was indirectly related, and only 23.4% considered their work had no relationship to the watershed. The majority of respondents had an income of less than US$ 10 per day, with half having less than US$ 5. Individuals considered as wealthy in the Chinese context (annual income more than ￥60,000) comprised less than 1% of the sample.

A comparison of the respondent characteristics with the Fujian population (Fujian Census, 2000), indicates that the respondents were typical of the watershed population in terms of percentage by reach, career, education background, age group, marriage status and income range. They also met the statistical assumptions of a Chi-square analysis for questionnaires.

Table 8-6. Characteristics of the questionnaire respondents.

Age group		Career		Years spent living in the watershed		Income range (Yuan/annually)		Marriage status	
18–29	11.69%	Government agency	31.3%	>30	57.0%	<12000	41.9%	Not married	11.0%
30–39	42.38%	Small enterprise	9.58%	20–30	21.8%	12–24,000	48.7%	Engaged	2.5%
40–49	33.41%	Large enterprise	6.35%	10–20	8.88%	24–36,000	5.46%	Married (without child)	5.36%
50–59	10.39%	Farmer	5.15%	5–10	5.43%	36–60,000	2.97%	Married (with child)	79.6%
60–69	1.53%	Self-employment	4.55%	1–5	4.56%	60–120,000	0.95%	Divorced	1.07%
70–79	0.59%	Others	43.11%	<1	2.34%	>120,000		Widowed	0.48%
	100%		100%		100%		100%		100%

8.3.2 Understanding of the general concept of a watershed

Experience suggests that many people do not have a clear idea of the environmental linkages that exist in a watershed, such as the connections between forest mismanagement, soil erosion, increases in runoff, and sedimentation in rivers and floods (e.g., Zhang, 2004; You, 2006). The first section of the questionnaire was designed to test a respondent's basic knowledge of the watershed concept, and their understanding of the importance of the watershed in their daily life. From the responses, it is apparent that 89.9% of respondents understood the concept of a watershed well. Amongst the responses, 23.2% believed that watershed management is a key factor determining water supply, 8.66% believed that watersheds also provide wood, agricultural, and aquatic products, and 18.3% believed that in addition, watersheds also provide other services such as hydroelectric power, biodiversity conservation, recreation, and carbon sequestration. 49.8% of respondents strongly believed that a high forest cover rate could enhance the way watersheds provide these goods and services.

When asked for their priorities in watershed management, 30.2% gave it to water supply, 24.1% to ecosystem and wildlife habitat, 15.3% to recreation, 14.9% to food security, and 14.1% to timber supply. These figures suggest that the stated concerns of the population are less on commodity supply and economic benefit and more on clean water and ecosystem protection. However, respondents were not asked to indicate whether they would be prepared to give up one benefit in favour of another. Of the factors negatively affecting the daily lives of residents, 47.8% of respondents considered water pollution to be the most important, and 34.0% indicated flooding. Other factors, such as drought, land degradation and invasive species, were scored less than 6%. The majority of respondents (60.8%) strongly considered that economic and environmental development should proceed simultaneously and with equal priority. 36.1% believed that environmental protection should be given top priority, whereas only 3.14% of respondents believed that economic development should be the top priority. This is remarkable given that the majority of respondents had average daily incomes of less than US$ 10. There was no indication of a significant gender difference in the degree of understanding of the watershed concept.

8.3.3 Awareness of watershed issues

Only 11% of respondents categorized the watershed environment as good or very good. Conversely, 44% of respondents considered that it was poor (29%) or very poor (15%), and 43.5% considered that it was neutral. Only 1.53% of respondents indicated that they were unsure. There was little evidence of any major differences in the perception of watershed development between the different reaches. Figure 8–1 shows the distribution of respondents' opinions toward the watershed environmental situation. The only major difference between reaches was the relatively high proportion of people (62%) from the middle reach who considered that there had been no change.

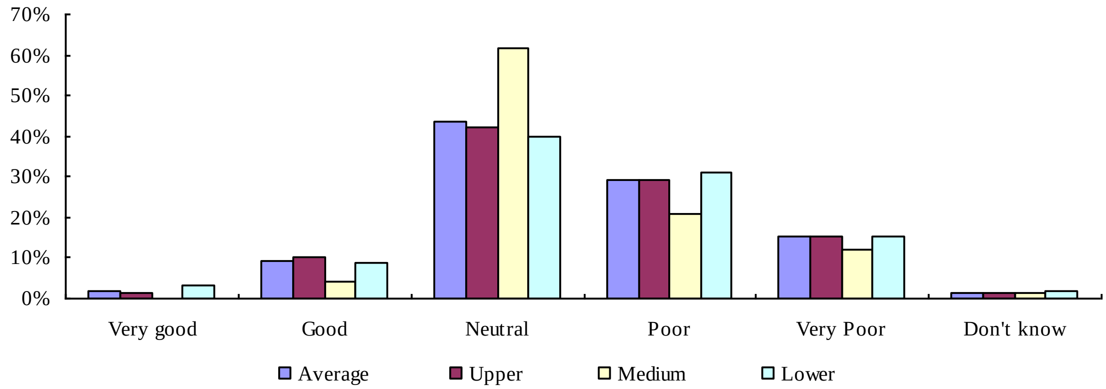

Figure 8-1. Overall opinions of respondents among the reaches on the watershed environmental situation.

There was evidence that those having a work-based relationship with the watershed were more likely to consider that the environmental condition of the watershed was improving (Table 8–7). These individuals generally thought that over the past 30 years there had been some (70.4%) or great (13.5%) improvement. In contrast, 94.6% of the people whose work was only indirectly related to the watershed considered that the environmental situation was deteriorating. The respondents from the general public (those without any direct or indirect links to watershed management) all believed that the watershed condition was getting worse, with 80.2% categorizing it as a major deterioration. Flooding and water pollution were identified as the two most important problems (Figure 8–2). These results reveal the bias inherent in most employment situations in China, namely the widespread belief amongst those directly involved in a project is not necessarily shared by those with lesser involvement.

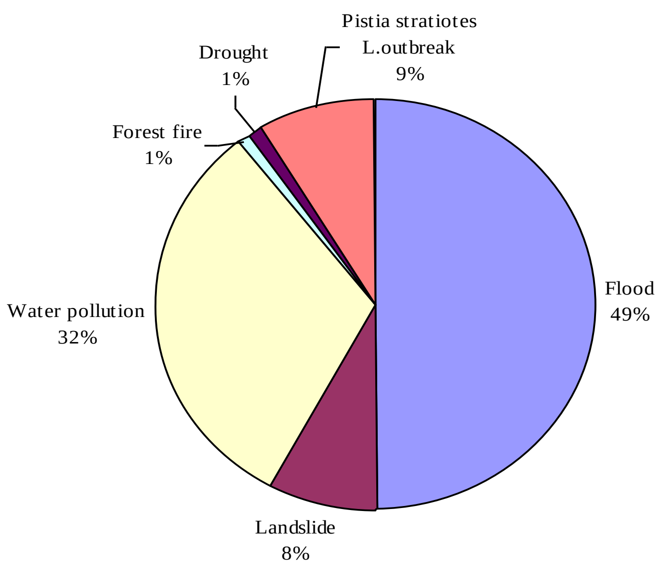

Figure 8-2. Opinions about the most important natural disasters in the past.

Table 8-7. Opinions of respondents about the direction of change in the watershed environment over the past 30 years.

	Direct	Indirect	No relationship	Average
Great improvement	13.5%			4.88%
Some improvement	70.4%			25.5%
No change	16.2%	5.37%		8.06%
Some worsening		94.6%	19.8%	43.2%
Major worsening			80.2%	18.3%
	100%	100%	100%	100%

(Note: Respondents were classified by their relationship to watershed management. "Direct" refers to respondents employed by watershed administrative/management institutions, while "Indirect" refers to those employed in watershed-related sectors).

In relation to the future development of the watershed environment, there was greater optimism in the middle reach than elsewhere, with the majority of people there either seeing no change or being more optimistic than those in the upper and lower reaches (Figure 8–3). It is perhaps significant that it is the middle reaches where the greatest problems with pollution occur, but the greatest impacts are in the lower reaches.

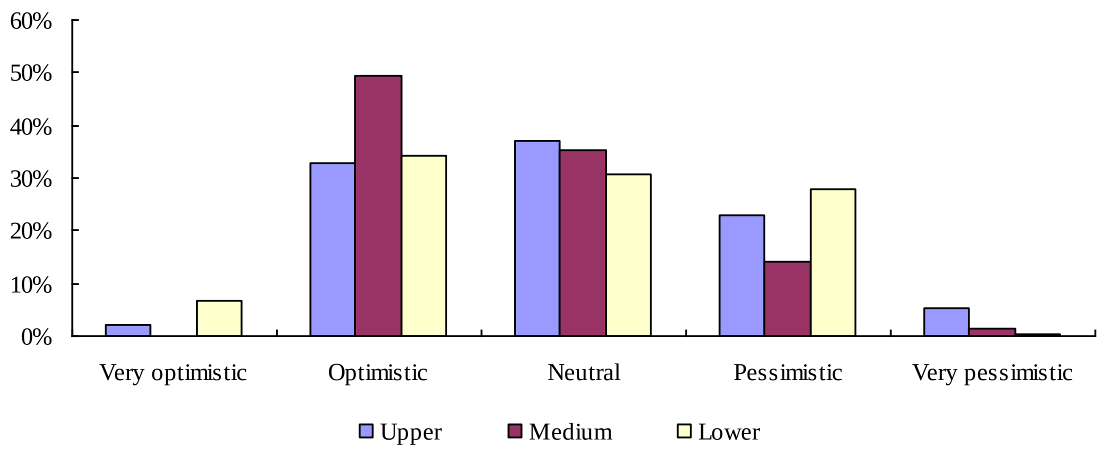

Figure 8-3. Opinion of respondents about future environmental changes in the watershed.

Although those working in watershed management considered that the environmental condition had improved while those not associated with management felt that it had deteriorated, there was no significant difference in their opinions about the likely future development of watershed condition (Table 8–8).

Table 8-8. Opinion of respondents about future environmental changes according to their relationship with the watershed.

	Direct	Indirect	No relationship	Total
Very optimistic	3.85%	2.47%	2.66%	3.01%
Optimistic	36.0%	35.8%	30.9%	34.7%
The neutral	35.7%	33.0%	38.3%	35.2%
Pessimistic	21.7%	25.0%	24.5%	23.7%
Very pessimistic	2.8%	3.7%	3.72%	3.38%
Total	100%	100%	100%	100%

(Note: “Direct” refers to respondents employed in watershed administrative/management institutions, while “Indirect” refers to those employed in watershed-related sectors).

The most important future concern was over water pollution (Figure 8–4). Flooding was ranked second in importance, five percentage points behind water pollution. Wildlife was listed as the third most important concern, ahead of drought, drinking water availability and land productivity.

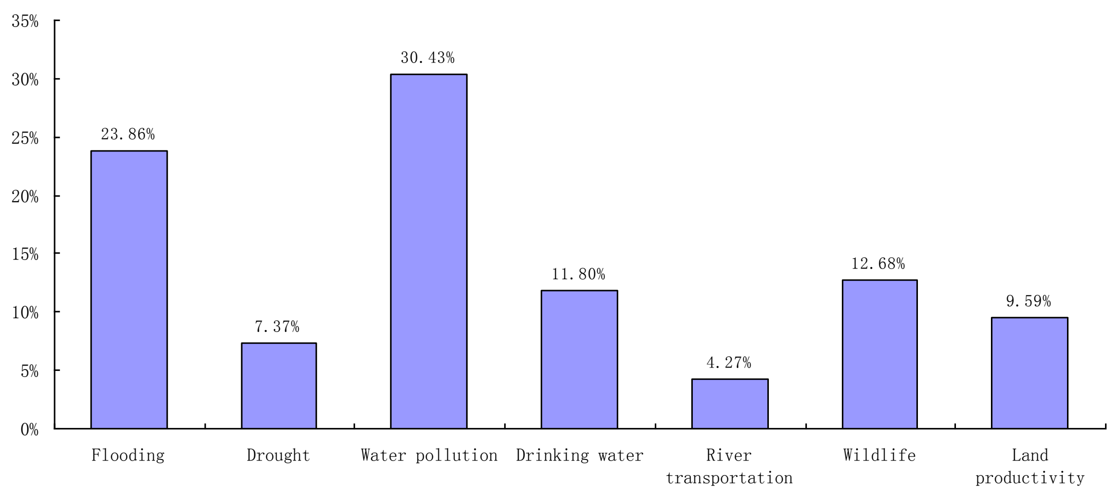

Figure 8-4. Level of concern about specific aspects of watershed management.

8.3.4 Understanding of the causes of watershed problems

Water pollution. Water pollution was one of the most important issues identified in the watershed, but there was considerable disagreement over the sources of the pollution. The results (Figure 8–5, standardized data for the all the rankings) indicate that untreated industrial and urban waste discharges were considered to be the major source of pollution. However, 595 respondents ranked untreated industrial waste discharge as the single most important source of pollution in the watershed (Figure 8–6).

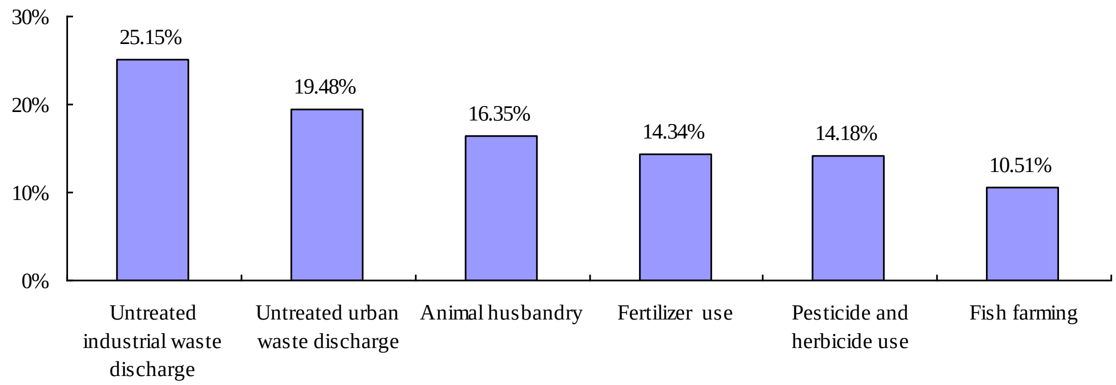

Figure 8-5. Sources of water pollution identified as important in the watershed. (Note: Respondents could indicate more than one source of pollution).

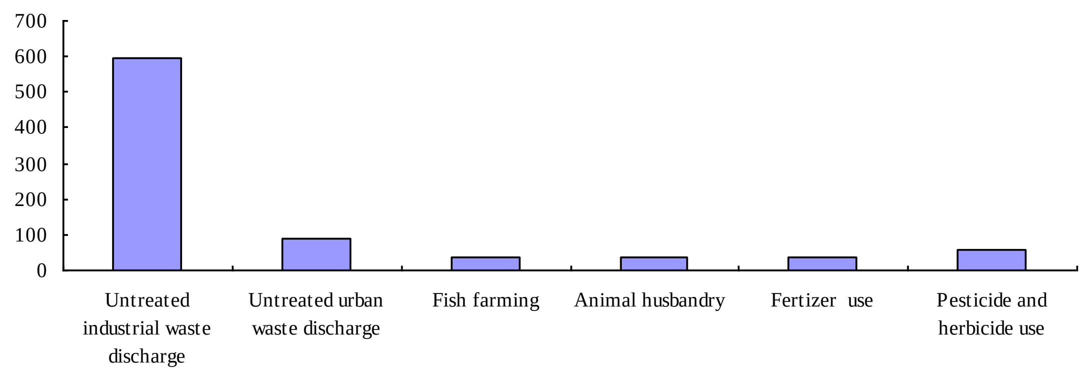

Figure 8-6. Number of the respondents ranking each element as the most important source of pollution in the watershed.

Flooding. The frequency of flooding in the watershed has increased over the past ten years. Historical records (Fujian Chorography Compilation Committee, 2002) indicate that in the 966 years between 982 AD and 1948 there were 235 floods in the watershed (one every 4.11 years). In the 70 years since 1948, there have been 20 serious floods (one every 3.5 years), Flooding has become more intense and severe since 1990, occurring almost every two years, and since 2000 there have been major floods almost every year. The most serious flooding in the recorded history of the watershed (since 1609) occurred in 1998, with 175 fatalities and 7 million people adversely affected. The total damage amounted to US$ 1.2 billion. As a consequence, flooding was ranked second (23.9% respondents) in importance amongst the issues facing the future of the watershed, five percentage points behind water pollution (Figure 8–4).

In terms of perceived causes (Figure 8–7, standardized data for all the rankings), the excessive logging of headwater areas was seen as playing a major role in flooding in the watershed. 65.0 % of the respondents considered that the reduction in the area of natural forest in the watershed was contributing to flooding while the other factors were all considered by less than 10% of respondents to be important.

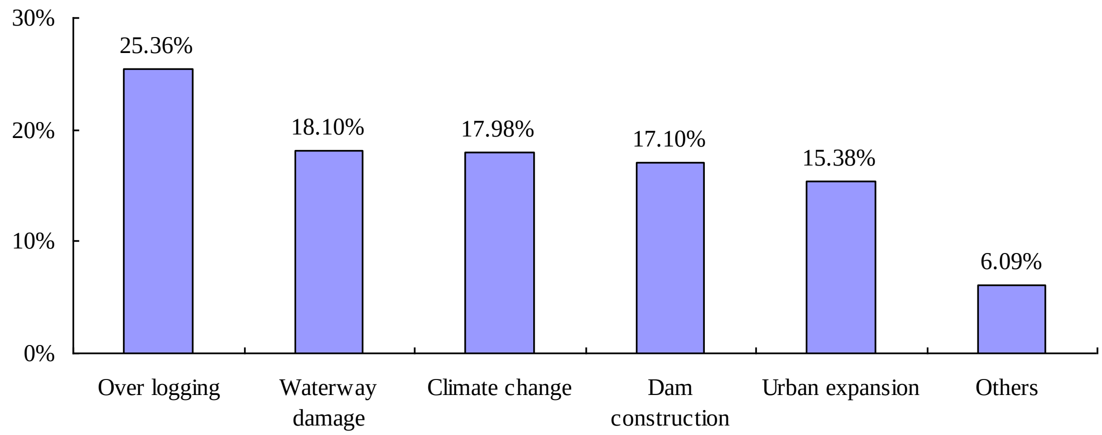

Figure 8-7. Perceptions of the main causes of flooding in the watershed according to survey respondents.

Soil erosion. Soil erosion was recognized as a major cause of sedimentation and land degradation. The questionnaire results (Figure 8–8) indicate that forest operations and agricultural development were considered to be the two most important causes of soil erosion. Forest silvicultural and agricultural practices and road construction were also believed to be contributing to soil erosion.

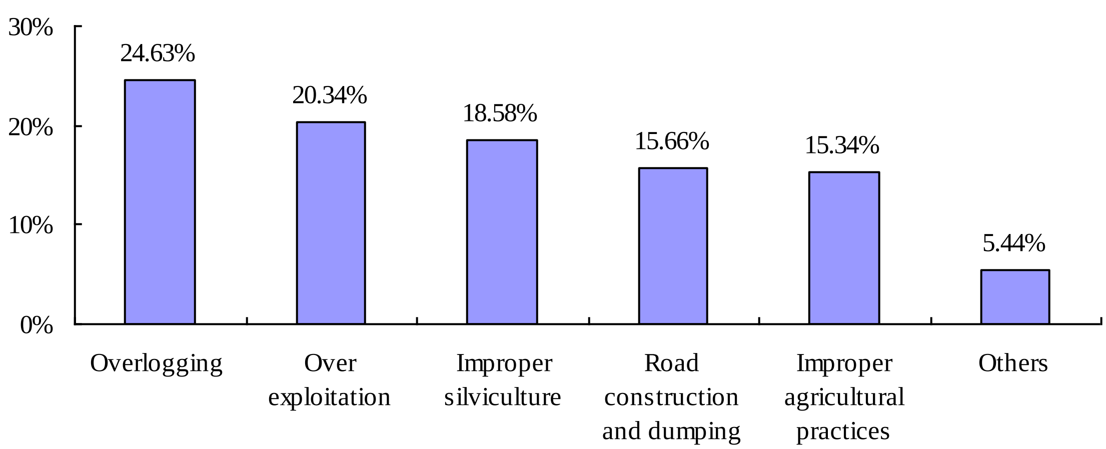

Figure 8-8. The main causes of soil erosion in the watershed according to the survey respondents.

Drought. In 2003, the watershed experienced the driest year in recent history, with precipitation being only 60% of that of a normal year. The reservoirs located along the river intercepted flow, concentrating water pollution and triggering outbreaks of water lettuce (*Pistia stratiotes L)*, a free floating herbaceous plant alien to China. Water lettuce covers the water surface and impedes water systems, navigation, and fish farming. The questionnaire revealed that over-logging was considered to be the main factor precipitating the drought (Figure 8–9), although the logic for attributing the drought to over-logging is unclear. There is no indication that the forest loss has been of a sufficient scale to affect local climates. Climate change was also believed to be playing a role, but of lesser importance than over-logging.

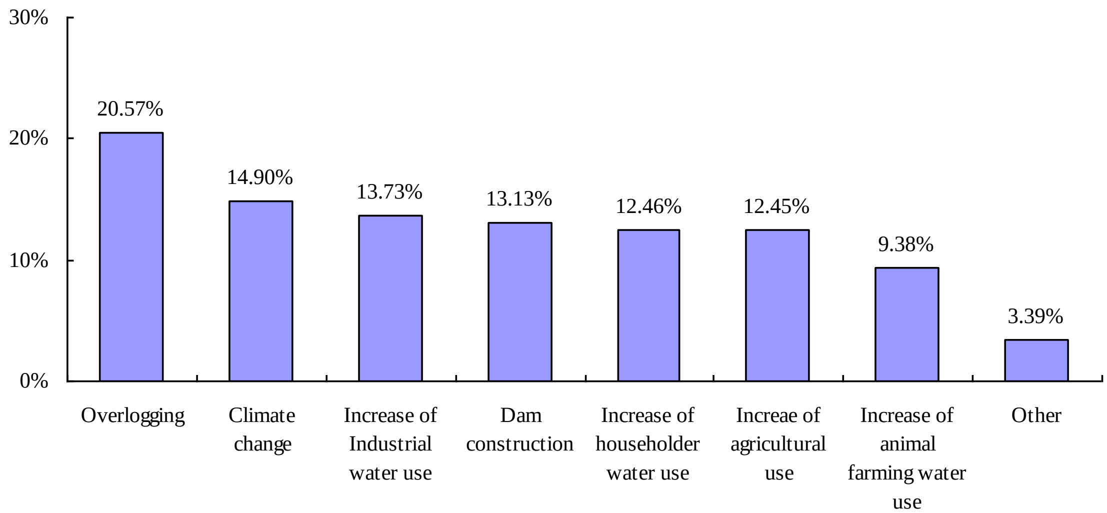

Figure 8-9. Perceptions of the main causes of drought in the watershed according to the survey respondents.

Invasive species. The survey indicated that respondents viewed that the outbreak of *Pistia stratiotes L.* in the Min River Watershed has greatly damaged water quality, irrigation, water transportation, and many other water-related activities (Photo 2). The Fujian provincial government has spent more than US$ 10 million on combating *Pistia stratiotes L.* since 2003, with only limited success. The reasons for the outbreak are complicated, and a variety of factors were identified by respondents as being involved, including sewage discharges, industrial waste, wastes associated with animal husbandry, fertilizer use and fishing farming (Figure 8–10).

The outbreak of Water Lettuce (*Pistia stratiotes L.)* completely clogging a reservoir on the Min River (Photo courtesy: Yun Yang).

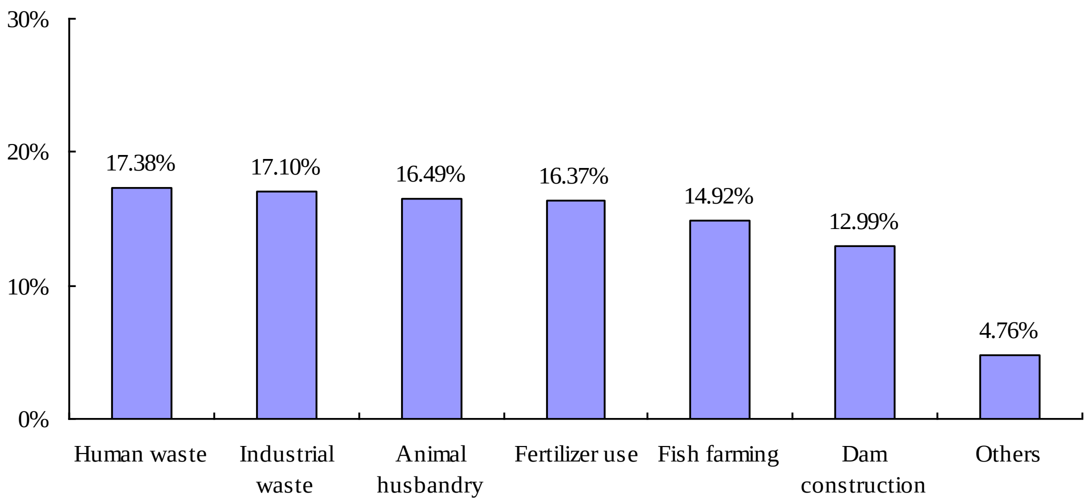

Figure 8-10. Major causes of the *Pistia stratiotes L.* outbreaks identified by survey respondents.

8.3.5 The importance of forest management

Forest management has been practised in the watershed for more than 2000 years, playing an important role its social, economic and environmental development. The Min Watershed was one of China's important timber supply areas from the 1950s to the 1980s, producing almost 10% of the national timber supply (Fujian Statistical Bureau, 20002). The loss of natural forest has been well-documented (Wang, 2008a). In 1987, Fujian province launched the Greening Barren Program to restore forest ecosystems through the use of large-scale plantations. However, improper silvicultural practices have actually aggravated soil erosion and land degradation (Wang, 2008b).

The questions about forestry generated mixed responses. Respondents were generally satisfied with progress in forest resource development in the watershed (Figure 8–11) and with the increase in forest area that has been achieved since 1998 (Wang, 2008a). The respondents also considered that the forest administration has done a good job in fire protection and resource management, forest inventory and pest and disease management. However, the respondents strongly believed that logging practices and riparian protection are very poor, and that they contribute to massive soil erosion. Respondents were ambivalent about the role of the forest administration in maintaining and enhancing stand and species diversity and in wildlife protection.

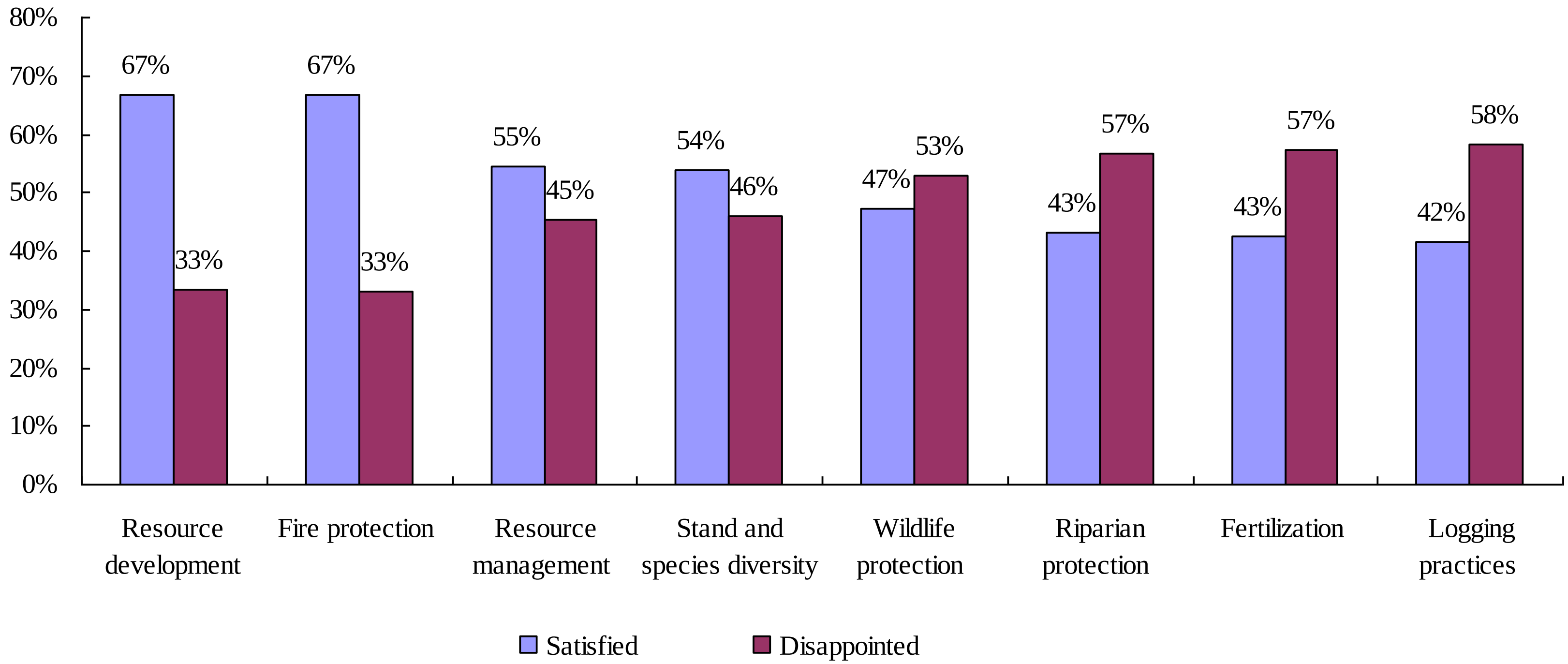

Figure 8-11. Comparison of the satisfaction with specific aspects of watershed forest management according to survey respondents.

The respondents believed that forest practices in the watershed are still poor (Table 8–9), with less than 10% considering that poor practices had been eradicated. Slash burning, the use of monocultures, herbicide and pesticide use, and an absence of riparian protection were all considered by respondents to be commonly practised. Although there is a ban on the logging of steep forested slopes, very large clearcuts and the harvesting natural forest still occasionally occur.

Table 8-9. Respondents' perceptions of the frequency of particular forest practices (%).

	Very often	Often	Sometimes	Very little	No longer practised
Burning	18.9	33.7	31.1	12.8	3.5
Tilling	7.26	21.1	39.4	25.3	7.02
Large-scale clearcuts	12.0	25.2	34.7	20.2	7.98
Monoculture	18.38	33.9	29.0	14.9	4.05
Inadequate riparian protection	13.4	27.1	33.7	17.6	8.29
Herbicide and pesticide use	16.1	34.3	28.1	17.3	4.29
Logging on steep slopes	11.0	24.2	34.9	21.7	8.26
Harvest of natural forests	10.1	19.2	34.9	25.1	10.8

Respondents believed that forest management lies at the heart of watershed health. When asked about the ecosystem services provided by forests, 81.7% believed that forests are central to balancing global ecological systems. 78.9 % believed that forests play an important role in maintaining clean water, air and soil in the watershed, and 63% considered they contribute to wildlife and ecosystem protection. Only 52.8% and 48.2% believed that forests are important for the economy and employment, and recreation, respectively.

8.3.6 The role of the governments in watershed development

About 70% of respondents believed that the government was not succeeding in watershed protection. More than 70% said that in their area, the local government did not have a watershed management plan. 66.4% of respondents believed that the cooperation of management agencies from the three different reaches was poor, and 10.7% considered it bad, with 69% believing that the agencies are actively uncooperative. Only 1% of respondents gave the government an excellent rating. Consultation during the government decision-making process was rated as poor, and 71.2% of respondents were dissatisfied with the level of consultation over large-scale watershed projects. Financial investment in watershed management was generally considered to be inadequate; 85.3% of respondents felt that the lack of financial support was a major issue. Funding for environmental protection was considered to be inadequate by 95.7% of respondents, and 96.9% of respondents felt that attempts to educate residents about environmental protection were inadequate. 81.2 % of respondents in the middle reach were disappointed at the level of cooperation amongst the reaches' governments, compared to 65% in the lower and upper reaches. However, a higher proportion of people (21%) in upper and lower reaches were very disappointed, compared to only 11% in the middle reach.

The twelve main government agencies involved in watershed management were viewed differently (Figure 8–12). High percentages of people believed that the Departments of Agriculture (61.6%), Fish Farming (57.2%) and Forestry (55.2%) were doing better than others. Disappointment was expressed over agencies dealing with pollution control (78.4%), waste discharge (73.8%), waterway protection (66%), water and soil conservation (65.2%), urban development (59.8%), road construction (55.4%), animal husbandry (55.3%), and disaster prediction and management (53.6%) (Figure 8–13).

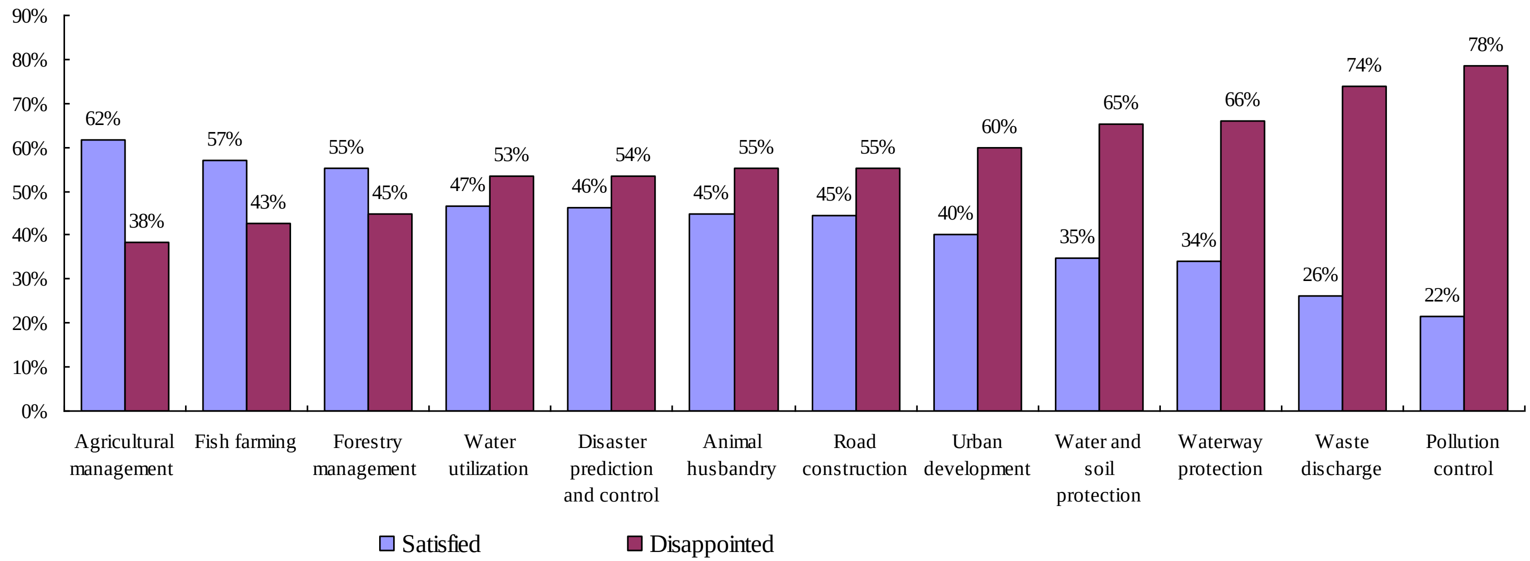

Figure 8-12. Approval rating for the twelve major government agencies dealing with watershed environmental protection according to survey respondents.

8.3.7 The willingness to participate in watershed conservation

The willingness of the public to participate in and contribute to watershed conservation is a key to sustainable watershed management. In recent years, democratic processes have gradually been introduced into local (village) level self-government and elections have been introduced at township and county levels. This increase in democracy has been accompanied by an increase in the availability of information, especially about the environment. At the same time, an increase in the number of environmental disasters and the revelation of their causes has greatly increased people's awareness of and concerns about development in the Min River Watershed. Many governmental and non-governmental websites have been launched to monitor environmental change and to provide instant information on significant issues.

Less than 5% of the respondents indicated that they had no interest in the watershed's environment. Almost half the respondents claimed to be greatly concerned about watershed health. More than 93.5% believed that they are a part of the watershed ecosystem, and 93.9% believed that their life-style, living habits and customs contribute to the overall health of the watershed.

Despite the strong interest in watershed conservation, only 1% of respondents (all of whom were watershed project managers) had actually participated in or had some involvement with watershed activities. Less than 11% of respondents had heard of or participated in some of the potential watershed activities. More than 87% of respondents had neither heard of nor participated in any public events related to watershed management. More than 78.8% of the respondents were willing to be involved in watershed decision-making, specifically to contribute their views or knowledge or to express their concerns. Less than 4.2% indicated no interest in such opportunities. 74.3% of respondents had encouraged their friends or family members to participate in public efforts related to watershed protection.

8.3.8 The willingness to contribute to watershed conservation

Cooperation amongst all watershed residents is critical to watershed protection. However, economic development is distributed inequitably in the watershed. Participants were requested to indicate their willingness to support development in other reaches. 83.6% of the respondents supported the idea that sectors with higher levels of development support the less-developed sectors, and 94% of the respondents were in favour of the lower reaches giving technical support to the upper reach. 92% of the respondents favoured giving financial support to the upper reach.

As indicated above, a substantial proportion of people in the watershed are living below the poverty line and are thus unable to contribute financially to the management of the watershed. 25.6% of respondents were reluctant to give support, primarily because they believed that watershed protection should be paid for by the polluters, rather than individuals, or should be paid for through government taxes. 57.5% of the respondents were willing to support watershed development financially, with the average level of support being 25.9 Yuan per month.

8.3.9 Suggestions for future development

The future direction of development in the watershed is clear. Sustainable watershed development is needed, but there was little agreement over the means to achieve this. Respondents were asked to rank the importance of seven practices: good planning, legislation for watershed protection, appropriate investment, an environmental surveillance system, inter-agency cooperation and inter-reach cooperation, public education and public participation.

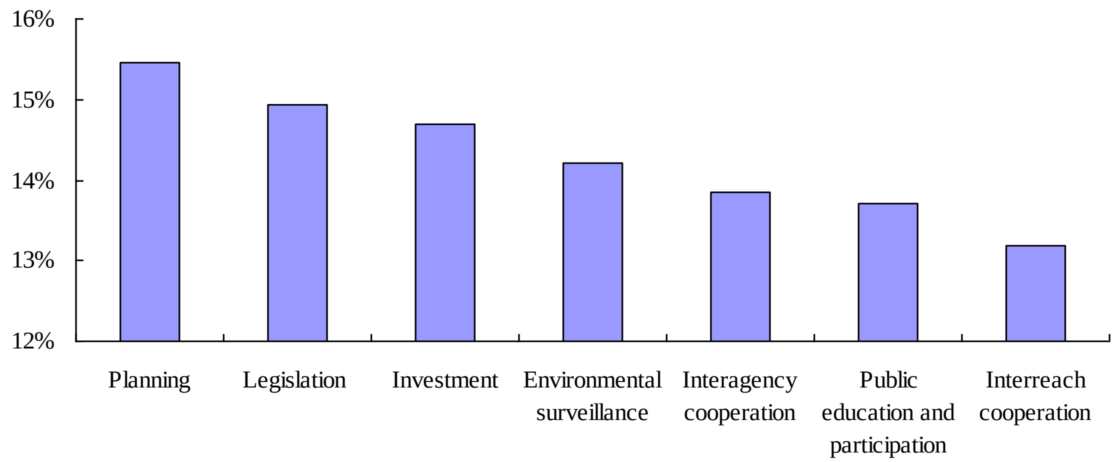

Figure 8-13. The importance of seven practices related to good watershed management according to survey respondents.

The standardized scores from the questionnaire indicate that most believed that good planning is important (Figure 8–13). This was followed by legislation and appropriate investment. However, the differences between the scores were small. Closer examination of the responses indicates that planning was ranked first by only 26.6% of the respondents (Figure 8–14), and that 23.1% ranked it as the least important of the seven mechanisms.

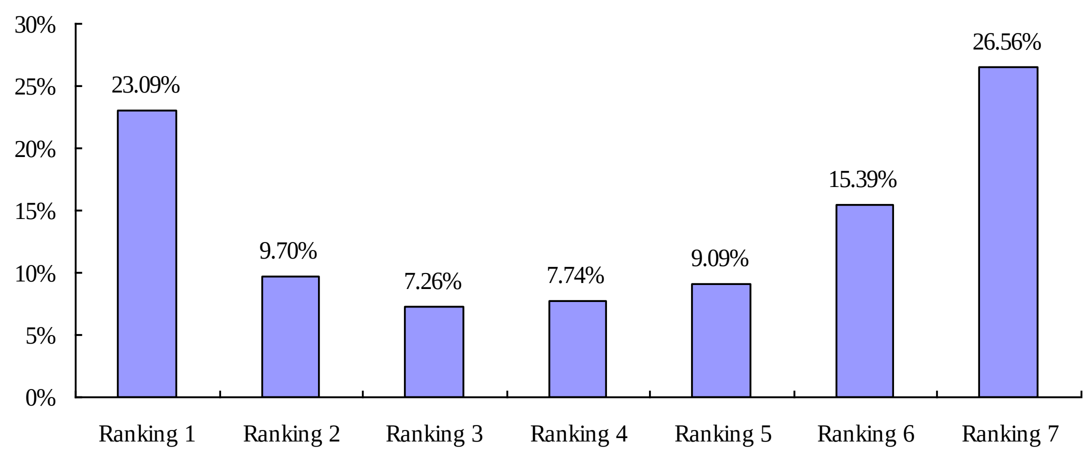

Figure 8-14. The ranking given to planning according to survey respondents.
A ranking of 7 indicates that a variable was considered to be the most important of the seven mechanisms.

8.4 DISCUSSION

The results of the questionnaire survey indicate that respondents were concerned about watershed health. Public awareness of environmental issues is quite high, and there seems to be a good understanding of the issues. Peoples' perceptions of the watershed can be related to their working environment. Their level of involvement and understanding of watershed issues and progress play a role in defining their perceptions. Those people working in watershed management tended to be able to view issues across time (temporal trends), whereas those not involved directly in management tended to make comparisons spatially (comparing one area against another). This was particularly evident in the answers to the question about environmental improvement over the past thirty years. The lack of any environmental education programs in the watershed is contributing to these problems.

The survey revealed that the main environmental concern about watershed management relates to water quality, with respondents placing watershed pollution as their top concern. Water pollution has impacted the daily life of many people, as many rural areas are still using water directly from the river without treatment. The odour of the water, human and livestock diseases associated with the use of polluted water, and outbreaks of *Pistia stratiotes L.* have greatly influenced the well-being of the watershed inhabitants. The recent increase in the discharge of untreated water arising from the rapid development of manufacturing such as pulp, paper, and fibre board mills, and the boom in livestock husbandry and fish farming along the river, have all exacerbated water pollution in the watershed.

The impact of flooding on the daily lives of people is different to that of water pollution. The increase in the frequency and intensity of flooding has resulted in thousands of people losing their homes. The causes of the flooding are complex. However, the respondents believed that over-logging of the natural forest has certainly played a role. Improper forest management practices have also played a role in soil erosion, sedimentation and land degradation, which in turn have contributed to flooding.

Human activities, such as construction activities, the dumping of waste into the river, and dam construction aggravate the risk of flooding. This is consistent with the findings of a number of other studies, such as Zhang (2000), Hong (2001), Zhang *et al*. (2000), Zhang (2004), Xie *et al*. (2004) and Wang *et al*. (2008a, 2008b).

A deterioration in the environmental situation is predicted if business is carried on as usual, despite the investments made by the provincial government. However, some improvements will be vigorously resisted if they adversely affect certain individuals, institutions or regional interests. The survey shows that public satisfaction with the level of cooperation between the governmental agencies involved in the protection of the watershed is very low. The majority of people believed that successful watershed protection will need better mechanisms for public participation, community involvement, the contribution of local expertise and knowledge, and the cooperation of multiple stakeholders across temporal-spatial and political boundaries.

The majority of people indicated that they would be willing to participate in watershed environmental protection in order to make the watershed a better place to live in. Residents were well aware of the contribution that the watershed makes to their general well-being and quality of life and felt that economic and environmental development should proceed simultaneously and with equal priority, or even that environmental protection should take priority because of the poor condition of the watershed and the risks that the entire ecosystem is facing. However, under the current system of governance, public participation is low. Respondents considered that there is no appropriate mechanism or channel for people to participate in decision-making or even to contribute their knowledge, nor is there any way for them to express their concerns about watershed construction projects that may affect their livelihoods or well-being. For example, the construction of the Shui Kou Electricity Power Station forced 67,000 people off their land and out of their homes. Although this occurred more than 20 years ago, the resettlement of those affected has not yet been officially completed.

In this research, the information obtained from the respondents has been confirmed by independent research on watershed land-use changes, the impacts of forest practices and watershed health (e.g., Xie *et al*., 2006; Chen *et al*., 2006). China is in a transitional stage of political, social and economic development. The respondents to the questionnaire indicated that the watershed management systems are not functioning properly. General reform of planning, legislation, public participation, inter-agency and inter-reach cooperation is needed, as is third party surveillance. Such a reform will only be possible if all the different stakeholders are brought together.

8.5 CONCLUSIONS

There has been an increase in the level of public awareness about environmental issues, but respondents indicated that more cooperation is needed. After thirty years of economic development and implementation of the Reform and Open-Door Policy, the Chinese public are gradually becoming aware of the importance of the environment and of environmental protection. However, with the increase in the magnitude and frequency of recent disasters, environmental issues are becoming the main concern of governments, enterprises, local communities and the general public (Yang, 2008). Despite these concerns, there are disconnections between government policies, construction projects and watershed protection. Given the poor level of cooperation amongst government agencies, a better mechanism is needed to facilitate such cooperation.

Watershed issues are mainly human-induced. Two major concerns were identified through the questionnaires: pollution and flooding. These are mainly caused by human activities, especially the discharge of untreated waste directly into water bodies, and over-logging of natural forests and inappropriate forest and agricultural practices. The combination of traditional practices, such as farming along the watershed, combined with modern mechanisation, such as the construction of industrial and intensive livestock facilities, have devastated the environment. Consequently, it appears that holistic and systematic development planning of the watershed should be promoted. Integrative efforts, including sound legislation for watershed protection, appropriate investment, an environmental surveillance system, inter-agency cooperation and inter-reach cooperation, public education and public participation seem to be needed if the goal of sustainable watershed development is to be achieved.

Public education and participation are key processes that will contribute to sustainable watershed management by enhancing public awareness and willingness. The different perceptions between the respondents from different working backgrounds indicated the inadequacy of public education on sustainable watershed management and environmental protection. People are willing to participate in and contribute to watershed development. However, there are no appropriate channels for this. The dialogue between decision makers and general public should be sufficiently flexible to enable public participation and community involvement. The contribution of local wisdom and knowledge, and the agreement of multiple stakeholders across temporal-spatial and political boundaries, are important to the successful development and implementation of watershed management planning, as has been shown in numerous other studies, such as Newson (1992), Shaxson (1997), Naiman and Bilby (1998), Wang (1999), Jones *et al*. (2002), Davenport (2003), Debarry (2004), and Palmer *et al*. (2004).

This paper has presented some of the preliminary results obtained by the questionnaire survey. A more detailed analysis of the differences between genders, reaches, education background, age groups and income range is being undertaken, and will be published separately. The very high return rate of the questionnaire is an encouraging sign of the potential of participatory mechanisms in watershed planning in China, and based on the results that we have obtained, we encourage the use of such techniques in China.

8.6 REFERENCES

Anderson, D.R., Sweeney, D.J. and Williams, T.A. 2002. *Statistics for business and economics*. 8th edition. South-western, Thomson Learning. Mason. USA.

Babbie, E. 2004. *The practice of social research*. 10th edition. Belmont, CA: Wadsworth

Bryman, A. 2004. *Social research methods.* (2nd edition). Oxford: Oxford University Press.

Chen, C.M. 2000. The impact of the industrial structure and distribution on environment around Min river basin. *Journal of Fujian Geography* 15(1), 14–17.

Chen, Y., Chen, J.F. and Chen, Z.Q. 2006. Comparative analysis of land use change between upstream and downstream counties of the Min River Watershed. *Soils* 38 (1), 48–52.

Davenport, E.T. 2003. *Watershed project management guide*. Lewis Publishers: Boca Raton.

Debarry, A.P. 2004. *Watersheds: Processes, assessment, and managememt*. John Wiley & Sons: New Jersey.

Enserink, B., Patel, M., and Kranz, N. and Mardtu, J. 2007. Cultural factors as co-determinants of participation in river basin management. *Ecology and Society* **12**(2): 24. [online] URL: http://www.ecologyandsociety.org/vol12/iss2/art24/

Elsasser, P. 2007. Do "stakeholder" represent citizen interests? An empirical inquiry into assessments of policy aims in the National Forestry Program for Germany. *Forest Policy and Economics* 9: 1018–1030.

Fujian Chorography Compilation Committee 2002. *Fujian chorography*. Fangzi Publishing: Fuzhou.

Fujian Environmental Protection Agency 2005. *The Min River water environmental protection initiative*. Fujian Environmental Protection Agency, Fujian, China.

Fujian Population Census 2001. *Fifth China national census – Fujian*. Fujian Bureau of Statistics of Fujian, Fuzhou, China.

Fujian Provincial Bureau of Statistics 2005. *Fujian statistical yearbook 2005*. China Statistical Publishing House: Beijing.

He, D. and Chen, J. 2001. Issues, perspectives and need for integrated watershed management in China. *Environmental Conservation* 28(4): 368–377.

Hong, W. 2001. *Forest ecology research in Min River valley*. Xiamen: Xiamen University Publishing House: Xiamen.

Huang Z.H. and Zhang D.L. 2008. A study on the construction of new socialist countryside that focuses on raising rural residents quality of life: Based on the survey of 1029 rural residents. *Journal of Zhejiang University (Humanities and Social Sciences)* 38 (4): 90–100.

Johnson, N., Ravenborg, H.M., Westermann, O. and Probst, K. 2002. User participation in watershed management and research.*Water Policy* 3 (6), 507–520.

Jones, C.R., Palmer, M., Motkaluk, S. and Walters, M. 2002. *Watershed health monitoring: Emerging technologies*. Lewis Publishers: Boca Raton.

Lum, T. 2006. *Internet development and information control in the People's Republic of China*. CRS Report for Congress.

Naiman, J.R. and Bilby, R.E. 1998. *River ecology and management*. Springer: New York.

Newson, M. 1992. *Land, water, and development: Sustainable management of river basin systems*. Second edition. Routledge: London.

Orr, P. Colvin, J., and King, D. 2007. Involving stakeholders in integrated river basin planning in England and Wales. *Water Resources Management* 12:331-349.

Palmer, M., Bernhardt, E., Chornesky, E., Collins, S., Dobson, A., Duke, C., Gold, B., Jacobson, R., Kingsland, S., Kranz, R., Mappin, M., Martinez, M.L., Micheli, F., Morse, J., Pace, M.,

Pascual, M., Palumbi, S., Reichman, O.J., Simons, A., Townsend, A. and Turner, M. 2004. Ecology for a crowded planet. *Science* 304(5675): 1251–1252.
Patel M., and Stel, J.H. 2004. *Public participation in river basin management in Europe: a national approach and background study synthesising experiences of 9 European countries.* Report of workpackage 4 of the HarmoniCOP project. Available online at: http://www.harmonicop.uni-osnabrueck.de/_files/_down/WP4SynthesisReport.pdf.
Report to Congress 2004. U.S –China economic and security review commission. http://www.uscc.gov/annual_report/2004/04annual_report.pdf
Shaxson, T.F. 1997. People's involvement in watershed management: lessons from working among resource-poor farmer. In: Rattan Lal. *Integrated watershed management in the global ecosystem.* Soil and Water Conservation Society. CRC Press: Roca Ratton. pp. 345–366.
SPSS Inc. http://www.spss.com/, and SPSS student version 15.0: for Microsoft Windows XP or 2000. (2006). Upper Saddle River: Prentice Hall Ptr.
Tindall, D.B. 2003. Social values and the contingent nature of public opinion, attitudes and preferences about forests. *The Forestry Chronicle* 79(3):692–705.
Wang, C.G. 2008. The urbanization and social structure change in China. *China Agricultural University Journal of Social Sciences Edition* 25(3): 55–66.
Wang, G.Y., Innes J.L., Liu J., Yu K.Y. and Yan K. 2008a. Watershed Pattern and change in land-use in the Min River Watershed, Fujian, China. *Land-Use Policy* , submitted.
Wang, G.Y., Innes, J.L., Hong, W., Ma, X.Q., Lin, S.Z. and Zhu, W. 2008b. Soil erosion associated with the establishment of Chinese fir plantations in southeast China. *Forest Ecology and Management,* submitted.
Wang, G., Innes, J.L., Yang, Y., Chen, S., Xie, J. and Lin, W. 2008c. Extent of soil erosion associated with large-scale infrastructure development and possible amelioration measures. *Catena*, accepted, subject to revision.
Wang, L.X. 1999. *Watershed management*. China Forestry Publishing House: Beijing.
Watts, J. 2003. China faces up to HIV/AIDS epidemic. *The Lancet* 362(9400): 1983.
Xie, J.S., Yang,Y.S. and Chen, G.S. 2004. The study on cause of flooding in the upper reach of the Min Watershed. *Fujian Water and Soil Conservation* 11: 12–17.
Yin, R.K. 2003. *Case study research: Design and methods*. Third Edition. Applied Social Research Methods Series, Vol. 5. Sage Publications, Inc.
You, X.W. 2006. The exploration, utilization and protection of the Min River Watershed. *Subtropical Soil and Water Conservation* 18(3): 89–91.
Zhang, C.X. 2004. *Study on forest ecological and social economic development in the Min River Watershed*. China Forestry Publishing House. Beijing.
Zhang, G..F., Chen, R.Y., Ceng, J.R. and Lin, W.G. 2000. A study on flood disaster and fragility of environment in Min River Valley. *Bulletin of Soil and Water Conservation* 20(4): 52–55.
Zhang, Z.X. 2000. The analysis of hydrological characteristics of Min Watershed. *Hydrology* 20(6): 55–58.

9 WATERSHED SUSTAINABILITY: STRATEGIC AND TACTICAL LEVEL ASSESSMENT IN THE MIN RIVER WATERSHED, CHINA[11]

9.1 INTRODUCTION

Watersheds provide a useful geographical scale for the sustainable management of natural resources. Watershed management involves the management of the socio-economic, human-institutional, and biophysical interrelationships between soil, water, and land use, and the connection between upland and downstream areas (Ffolliott et al, 2002). Davenport (2003) has suggested that the watershed management process is the primary mechanism available to relate science, policy, and public participation to water resources management. However, with the governance system adopted in China, these three aspects of management are not given equal weighting. This was clearly evident in the responses to a questionnaire administered to the residents of a major watershed in China (Chapter 8).

Over the last 100 years, there has been an increase in population along the Min River; as a consequence, the watershed has been intensively used for resource production (Zhu, 2001). Traditional forest management practices in the watershed involved adverse practices such as clear-cutting and soil tilling, litter-raking, large-scale monoculture plantations, and logging without leaving buffer zones along riparian areas (Yu, 1999; Lin *et al*., 2001). Traditional agricultural practices with adverse environmental impacts included planting crops on steep slopes, using tilling to control weeds in tea and fruit orchards, and the heavy use of herbicides, pesticides, and fertilisers to increase productivity. In recent years, fish farming in paddy fields and reservoirs has become a major source of water contamination (Fujian Environmental Protection Agency, 2006; Duan *et al*., 2007). Improper management and over-exploitation of agriculture and plantations has led to the degradation of ecosystems and widespread soil erosion and sedimentation. The degradation of the watershed's ecosystems has lowered soil productivity and increased water contamination (Zheng, 1999; Wang and Zhu, 2007).

The concept of sustainable forest management was introduced into China in 1992 after the United Nations Conference on Environment and Development. However, there have been many problems associated with the adoption of western systems of management. While theory abounds, in reality it is extremely difficult to balance the sustainable use of limited natural resources with high population densities and accelerated economic development. To address these concerns a Regional Sustainable Development Assessment (RSDA) approach (such as adopted by Liu and Shen, 1997; Kasemir et al., 1999; Robert et al., 2002; Sustainable Development Research Group of China Academy of Science, 1999, 2000, 2001, 2002, 2003) was used to examine the sustainability of development in the Min River watershed from 1991 to 2002.

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[11] A version of this chapter has been published. Wang, G.Y and Innes, J.L. 2005. Watershed sustainability: Strategic and tactical level assessments in the Min River Watershed, China. Environmental Informatics 3: 76-83. At the request of the external examiner, the version presented here differs significantly from the published version.

The analysis also included the spatial and temporal trend of development in the watershed. An Auditing Systems of Sustainable Forest Management (SFMCAS) (e.g., Appanah and Kleine, 2001; Long, 2006) was also used to examine the impacts on, and mechanisms for, human–watershed interactions at various management levels.

9.2 STUDY AREA

The Min River is located in southeast China, from 116°30' to 119°30' E and 25°20' to 28°25' N. It is the largest river in Fujian Province and is one of the largest ten rivers in China. Because the watershed has a typical flabellate structure, the upper reach of the watershed can be divided into three areas – headwater, middle valley and lower valley, and then middle and lower reaches. The headwaters of the Min River are situated at an elevation of approximately 2115 m in the Wuyi Mountains, which are located in the northwest section of Fujian (Figure 1–1). Flowing generally east through Sanming, Nanping and Fuzhou cities, the watershed covers an area of 60,000 km^2 and is 2872 km in length; the main river has a length of 584 km. The Min River plays an important role in the social and economic development of Fujian province.

Almost a third of Fujian's population of approximately 12 million people inhabits the watershed. It accounts for over 50% of the province's total agricultural production, 66% of the commercial logging (Fujian Statistical Bureau, 2007), and 60% of the drinking water in the province (Fujian Chorography Compilation Committee, 2002). The water is used for generating hydroelectricity for urban and industrial use, irrigation, flood control, navigation, recreation, fishing, industry, and wildlife conservation. The largest construction project is the Shuikou Hydropower Station at Minqing County, which produces 1.4 million kilowatts annually. Apart from generating power, the dam is expected to help control flooding in the Min River Watershed.

In recent years, over-cutting and forest burning in the watershed has led to soil erosion, stream sedimentation, flooding, increased run-off, and a reduction in land productivity (e.g., Hong, 2000; Zeng *et al*., 2003). The annual timber production has been reduced almost 5 million m^3, or 50% in the watershed since 1950; the changes over time have not only reduced the economic benefits received from wood products, but have resulted in a significant lowering of the quality of forest ecosystems. Soil erosion and sedimentation have resulted in the annual sand load of the river rising from 7 million tonnes in the 1950s to over 20 million tonnes in the 1990s (Zeng, 2003). Since 1992, Fujian has been suffering massive social, economic and environmental damage resulting from flooding that has been exacerbated by logging in the watershed (You, 2006; Chen *et al*., 2006). The flooding in 1998 alone cost the province US$ 1.2 billion (Fujian Chorography Compilation Committee, 2002).

The issues in the watershed are of great concern to the government and public (Fujian Environmental Protection Agency, 2002). Several government departments and bureaus such as Agriculture, Forestry, Water Conservation and Environmental Protection, and Ocean and Fisheries have put great efforts into a project called "Comprehensive Plans for Harnessing the Min River". The project was formed and initiated by the Fujian Provincial Government in 1995; since then more than one million dollars have been invested in the project annually. Many institutions, including government organizations, NGOs, and hundreds of independent researchers have conducted studies in different research areas. Zhao (1997) conducted a hazard assessment for mountain torrents in the upper reaches of the river. He identified the triggering factors, propagating processes and spatial distribution of damage caused by mountain torrents. Zhang (2000) analyzed floodwater distributions and the environmental fragility of the Min Valley. He argued that the degradation of the forest ecosystem had dramatically decreased water retention and soil conservation in the watershed over the last 30 years. Chen (2000) described the impacts of the industrial structure and distribution on the environment around the Min River basin. Because most heavy and metallurgical industry in the province is concentrated in the Nanping and Sanming areas, the upper reaches of watershed account for more than 80% of water and air pollution in the watershed. He suggested that future industrial developments should be regulated by Provincial legislation. Liang (2002) analyzed forest resources in the watershed and the relationship between soil erosion and forest cover. The different vegetation types and quality of vegetation in riparian areas had a major impact on rates of river sedimentation. He pointed out the importance of establishing riparian and soil protection forests. Pang (2003) identified that intense precipitation combined with the unique landforms in the area, the malfunctioning of the reservoir water control system, and over-cutting of forests were the main causes of flooding in the Min River. He suggested avoiding such events by increasing public awareness, increasing coordination between agencies, and developing a better system of watershed management. He also proposed increasing investment in eco-forestry development and management along the Min River. However, very few researchers have adopted a watershed scale to look at the mechanisms responsible for ecosystem degradation, increased natural disasters, and social problems. In addition the measures required to achieve sustainable development in the Min watershed have not been examined.

9.3 METHODOLOGY

9.3.1 Sustainable development indices

There are very few tools that can be used for a regional watershed sustainable development assessment. The UN Human Development Index (HDI) measures poverty, literacy, education, life expectancy, and other factors (e.g., United Nations Development Programme, 1999). It has become a standard means of measuring well-being, especially child welfare (Purohit, 2005). The index was developed in 1990 by Mahbub ul Haq and has been used since 1993 by the United Nations Development Programme in its annual report. The Pressure–State–Response Index System (e.g., UN Commission on Sustainable Development, 1996) has been adopted by the UN Commission on Sustainable Development, the UN Department for Policy Coordination and Sustainable Development, UNSTAT, and the Scientific Committee on Problems of the Environment of ICSU. While the system has advantage of highlighting the links of Pressure-State-Response, However, it tends to suggest linear relationships in the human activity and environment interaction. This should not obstruct the view of more complex relationships in Ecosystems and in environment and economy interactions (Segnestan, 2002). The PRED (population, resource, environment and development) sustainable development index systems and the Three Dimensions Integrative Development Model are also popular tools for the assessment of sustainability. However, these models are mainly used for large-scale broad-spectrum assessment and comparison, and it is difficult to quantify the input-output/outcome-impact at a watershed level.

Many RSDA approaches are currently in use (e.g., Sarageldin, 1996; Neumayer, 2001; China Sustainable Development Research Group, 1999–2003; Li *et al*., 2007). However, most are focused on the assessment of national-level performance. The approach that we have used here is a hybrid approach that integrates economic, ecological and social development into the watershed hierarchical system.

The structure of the sustainable index systems (SIS)

The SIS uses both temporal assessment and spatial assessments (Sustainable Development Research Group of China Academy of Science, 1999). The spatial assessment is used to examine spatial differentiation of sustainability and the possible interactions between the upper, middle, and lower reaches. The temporal assessment involves the analysis of ten years of development in the watershed in order to determine if the management practices over the past 10 years have been sustainable. The index systems comprised an objective layer, principles, criteria and indicator layers (Liu and Shen, 1998, and Li, et al., 2007). The objective is to achieve sustainable watershed management. The principles comprise three components related to the objectives: economic development, ecological development and social development.

Criteria and indicator determination

For determination of the regional sustainable trend (from 1992–2002), we used the expert evaluation method (Dalkey, 1969) to determine the weights of the criteria and indicators. The Delphi process was applied to select and score the watershed management index system. The proposed 50 indicators were based on literature reviews and experience and were distributed by mail to a panel of 30 well-known scientists (10), economists (5), environmentalists (5), government officers (5), and community leaders (5) in the region. After collecting and analyzing the first round responses, a meeting was held to seek consent on the structure of the criteria and indicators as well as on the score for each criterion. Again, the responses were classified and summarized and then returned to each participant for review. The process of the reclassified-summarized- returned was repeated three times, and then consensus was achieved. 20 indicators for temporal comparison (Table 9-3) and 10 indicators for regional comparison (the spatial comparison) (Table 9-5) were chosen. We compared the sustainable development for the three regions in the watershed: the upper, middle and lower reaches using 11 counties (cities). The panel was also asked to give a relative priority to each criterion for the weighting determination in the Analytical Hierarchy Process. The details are discussed below. The arithmetic mean was derived from the two results.

Weight determination for the criteria and indicators

We employed the Analytical Hierarchy Process (AHP) (Saaty, 2000) to determine the criteria and indicators for the temporal assessment. We used an Improved AHP (Jia and Liu, 2003), which uses a 3-point scale system to determine the weights of the indicators and criteria. The following is the three steps of the AHP process:

Step 1: Construction of a subjective and comparative judgment matrix:

$$C = [Cij]nxm$$

$$Cij = \begin{cases} 1 & \text{Indicator i is more important than indicator j} \\ 0 & \text{Indicator i and j are the same} \\ -1 & \text{Indicator i is less important than indicator j} \end{cases}$$

Where

n - number of criteria

m - number of county

Step 2: Development of a subjective judgment matrix:

$$S = [Sij]nxm$$

where $Sij = di - dj, \;\; di = \sum_{j} Cij$

Step 3: Development of an objective judgment matrix:

$$R = [rij]nxm$$

where $rij = P^{(Sij/Sm)}, \;\; Sm = \underset{i,j}{Max}Sij = \underset{i}{Max}(di) - \underset{j}{Min}(dj)$

P is a user-defined value scale, for example, P = 3 or 7, here we use 3.
Standardized values of a random row, in the objective judgment matrix, are n criteria weight vector quantities [w1, w2,…., wa]T. The sum of all the indicators beneath a given criterion in each tier of the model must equal one. The weightings for the criteria and indicators are listed in Table 9–1.

The sustainable indices computation
Data collection: The data were collected from Fujian Provincial professional surveys (Mainly from the Fujian and Ecological and Environmental Survey in 2002) and the Fujian Statistical Yearbook for the years 1991 to 2003.

Data standardization: When x is a positive factor

$$y_i = x_i / s_i$$

When x is a negative factor

$$y_i = 1 - \left| (x_i - s_i) \right| / s_i$$

where: y is the standardized value
x is the value from the raw data

s is the subjective value based on Fujian Sustainable Development Action Plans (Fujian Provincial Government, 2000).

Three key sustainable indices computation as follow:

1). Social, economic and population development index (di) computing:

$$di = \sum_{i=1}^{n} w_i y_i$$

where: w_i, y_i represent the social, economic and population

2). Environment and resources constraint index (re) computing:

$$re_i = r * \sum_{i=1}^{n} w_i y_i + e * \sum_{i=1}^{n} w_i y_i$$

where: w_i, y_i, present only the environment and resources

r, e are the weights of the resource and environment

3). Comprehensive appraisal criteria computing:

The sum of the standardized criteria yi times its weight wi for z -value of the sustainable development:

$$z_i = (a * di + re_i)/2$$

$$Z = (z_1, z_2, z_3 .... z_i)^T$$

Sustainable development analysis:

1). For the temporal comparison: each z_t value was used to compare the values from Table 9–1 to identify the level of sustainability.

Table 9-1. Sustainable Development Index Level for temporal comparison (Source: Chen, 2004).

Category of sustainability	Degree
Very low	<0.30
Low	0.30–0.44
Moderate to low	0.44–0.59
Moderate to high	0.60–0.74
High	0.74–0.89
Very high	0.90–1.0

2). For spatial comparison of the differences among reaches: we used four classification levels (Table 9–2): very good, good, average, and poor based on the standard deviation and the mean value:

(I = (average- individual value) / standard deviation)

Table 9-2. Sustainable Development Index Level for the spatial comparison.

Category of sustainability	Degree	Description
Very good	$I \geq 1$	larger than average + 1 standard deviation
Good:	$1 \geq I \geq 0$	between average + 1 standard deviation and average
Average	$0 \geq I \geq -1$	between average and average- 1 standard deviation
Poor	$I \leq -1$	less than average- 1 standard deviation

9.3.2 Sustainable Forest Management Certification Auditing Systems

SFMCAS was adopted and put it into practice in 2001, in Fujian, China after the International Seminar for Sustainable Forest Management Certification Auditing Systems held in Zhangzhou city, China. The seminar was co-sponsored by the Forestry Research Support Program for Asia and the Pacific of the United Nations Food and Agriculture Organization, the Chinese Academy of Forest Science and Fujian Department of Forestry (Wang and Yang, 2001; Yang and Wang, 2001). An auditing approach is a key step in the Sustainable Forest Management certification process. The approach is based on the regional sustainable forest management (SFM) criteria and indicators that carefully examine all aspects of forest management, including the social, environmental and economic dimensions that may be impacted or potentially impacted by forest management (Appanah and Kleine, 2001).

This SFMCAS approach was originally developed by the International Tropical Timber Organization (ITTO, 2000) for assessing sustainable forest management certification. SFMCAS was used to assess the sustainable management and development of the area, as the watershed is dominated by forests. Forest practices also significantly contribute to the local economic and community development such as wood supply, revenue generation and facility building. The difference between the SFMCAS approach and a traditional monitoring and evaluation system is that the auditing system is based on a set of criteria and indicators which cover not only regional forest management and management policy, but also the region's political, social, economic, and environmental condition. In contrast, traditional monitoring largely focused on timber sustainability. Another important point used in the selection of the SFMCAS is that the auditing introduces the mechanism of third party assessment rather than assessment via government forest management agencies. Traditional monitoring is a self-assessment and improvement system that propagates a lack of responsibility, fairness, and reliability.

We used the Fujian Forest Sustainable Forest Management Criteria and Indicators (Yang and Wang, 2001). These are based on specific ecological areas (subtropical forests), the socio-economic condition of the Min River Watershed, experiences in the Jiulong River area, and an international SFM criteria and indicators (C&I) framework (the Montreal Process).

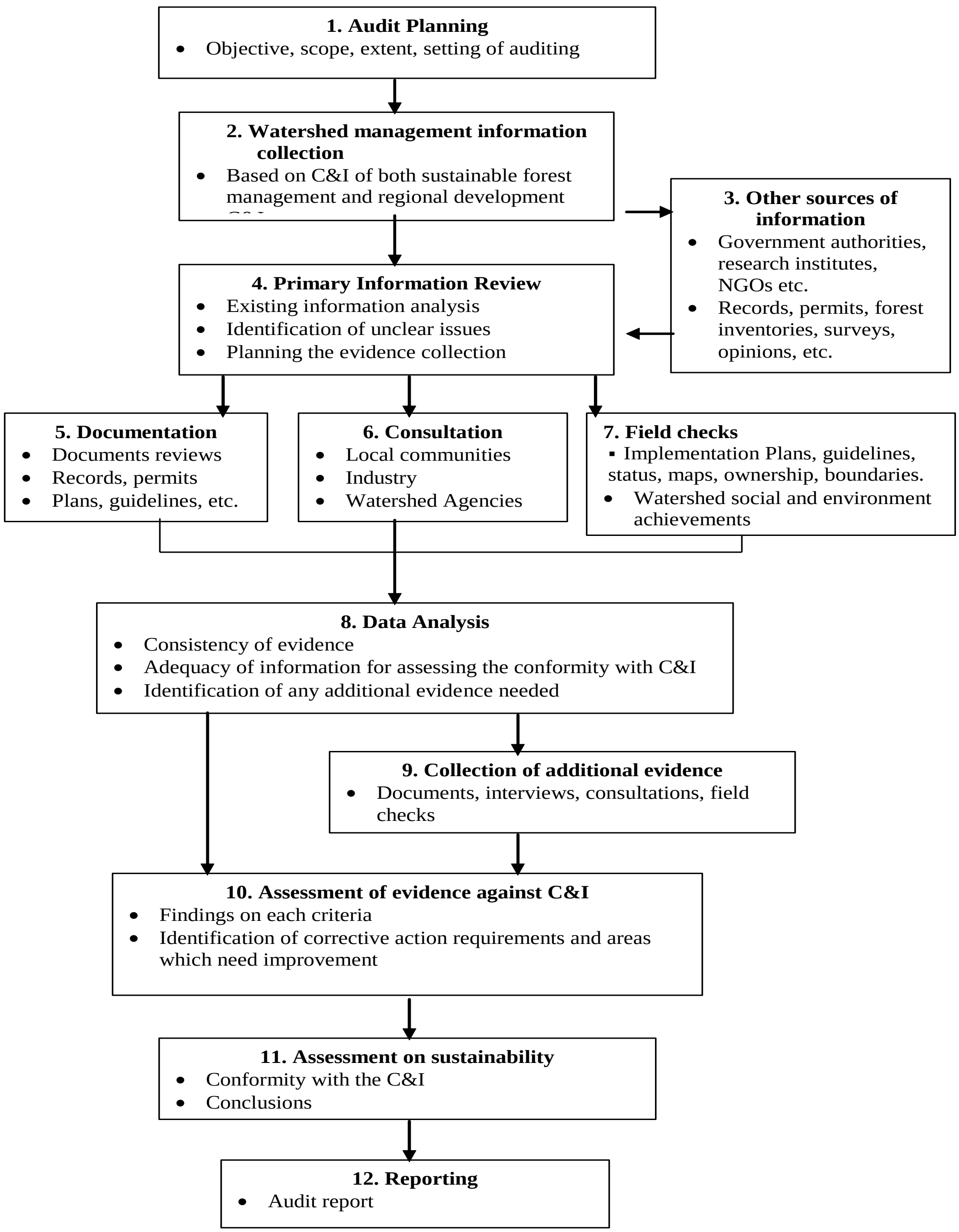

Figure 9-1. Flowchart for the SFMCAS approach (Adapted from ITTO, 2000).

9.3.3 The integration of SFMCAS with RSDA

The RSDA is a results-based assessment that focuses on social, economic and environmental achievement to evaluate a region's state of sustainability. The SFMCAS is a ground-level process-based assessment tool. It enables a researcher to look at the mechanisms behind the RSDA, which provides an understanding about what is actually happening in the field.

Both scales are necessary for assessing sustainability at the watershed scale. The RSDA operates at a higher level and allows the social, economic, and environmental outcomes and development trends (interaction of the four dimensions – social, economic, environmental and temporal) to be evaluated. The RSDA provides strategic-level thinking and decision making. The SFMCAS is a low-level and practical tool for examining the performance of each criterion and indicator. The scale that the SFMCAS operates at provides detail for management-level planning. The integration of the two approaches will allow a holistic regional assessment and an analysis of both tactical management and strategic planning within the watershed.

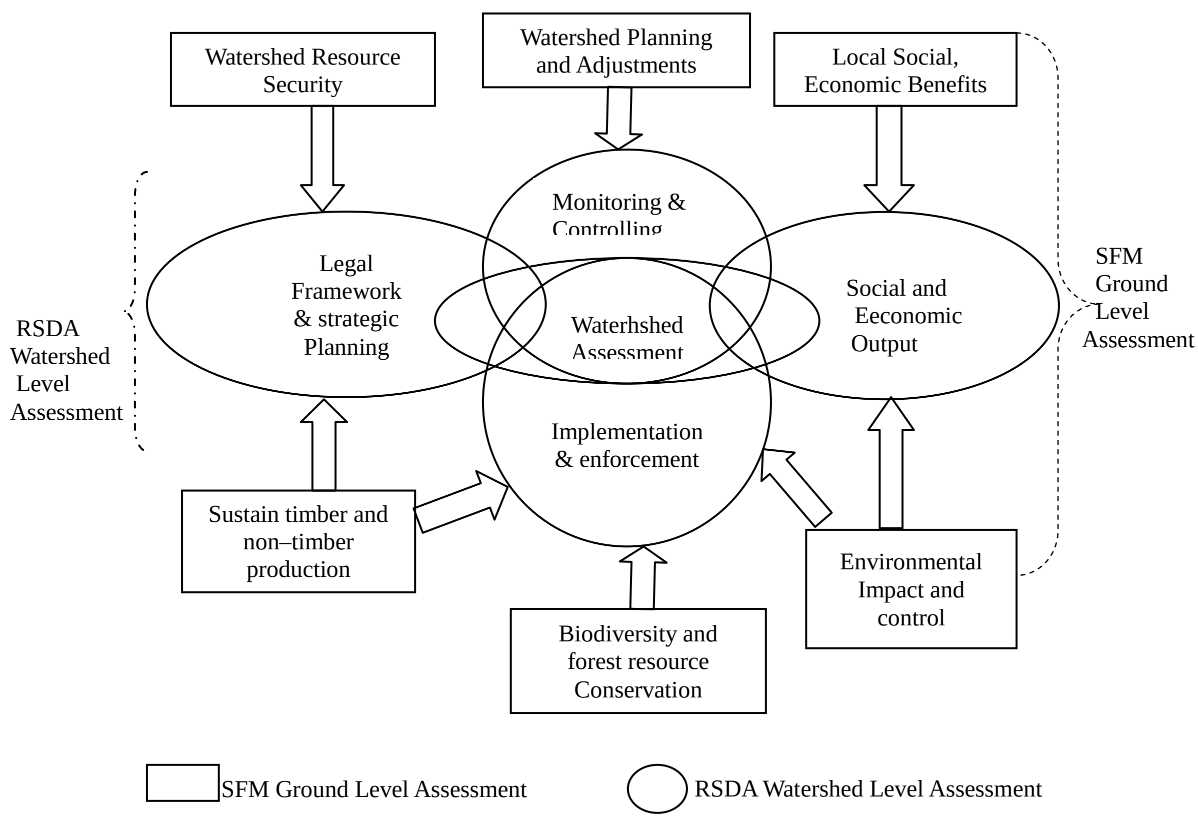

Figure 9-2. The integration of SFMCAS and RSDA.

9.4 RESULTS

9.4.1 Regional Sustainable Development Assessment

The temporal assessment. Table 9–3 shows the criteria and indicators for temporal assessment, as based on the Analytical Hierarchy Process. Table 9–4 shows the trend of watershed sustainability. Since 1991, the index has had a value in the range of moderate to low.

Table 9-3. Indicators and weights.

	Criteria	Indicators and measurements	Weight
The degree of development (0.446)	Economic development (0.505)	GDP per capita	0.326
		Income per capita	0.258
		Industrial GDP	0.218
		Engel's index	0.198
	Social development (0.208)	Percentage possessing social insurance	0.333
		Gini index	0.384
		Housing per capita	0.283
	Population (0.287)	Percentage with a secondary degree	0.383
		Natural growth rate	0.398
		Illiteracy %	0.219
Resources capacity (0.304)	Resources constraints	Arable land per capita	0.335
		Forest cover	0.223
		Hospital beds per thousand persons	0.208
		Electricity power consumption per capita	0.234
Environmental capacity (0.250)	Environmental constraints (0.42)	Effective irrigation land	0.463
		Precipitation	0.277
		Dryness index	0.260
	Pollution control (0.58)	Use of fertilizers	0.210
		Percentage of water pollution treatment	0.385
		Percentage of waste gas treatment	0.405

Table 9-4. Sustainable development index.

Index	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Development index (di)	0.01	0.08	0.18	0.21	0.23	0.23	0.41	0.44	0.46	0.58	0.61	0.61
Resource and environmental index (re)	0.59	0.61	0.61	0.58	0.59	0.63	0.63	0.64	0.63	0.67	0.68	0.68
Sustainable development index (zi)	0.32	0.37	0.41	0.41	0.43	0.45	0.53	0.55	0.55	0.63	0.64	0.65

The RSDA analysis identified that watershed development has progressed quickly in the last 10 years. Development is in the right direction, but it is still scored at the low to middle level. Comparing the trend for environment and resources with the development trend (Figure 9-3), we found that the two lines almost meet. This means that initially, development is based on the use of resources and that damage to the environment ensues. In the last 10 years, the environment and resources have not improved.

The analysis (see Figure 9–3) revealed that development has increased dramatically over the last decade, by approximately 60%. Fortunately, the resources and environment still have potential for further development and improvement. The general environmental conditions, such as forest cover and pollution control are improving, but the accessible resources, such as harvestable forests and arable land quantity and quality are being significantly depleted.

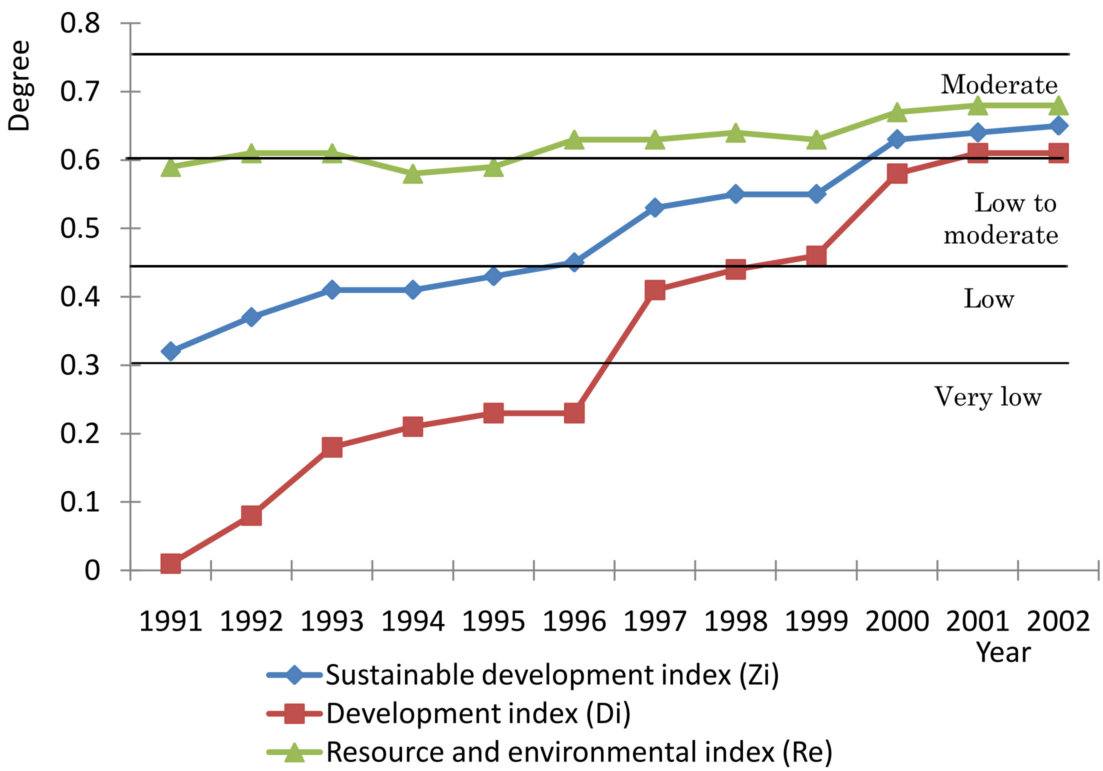

Figure 9-3. The trend in watershed sustainability between 1991 and 2002.

The spatial assessment. The criteria and indictors (see Table 9–5) are broad and represent the watershed *status quo* very well. The data used in the spatial assessment were collected from the Fujian Provincial Statistics Yearbook (1998–2002). In order to minimize the differences among the years, we used the average values of the data from the time period. Table 9–6 reveals that the sustainable development values for the 11 counties in the watershed fell in the range of low or moderate to low sustainability rating. The results suggest that regional development in the watershed is uneven. The sustainability of the upper reach headwater, the middle reach, and the lower reach are in the same group, and that the upper valley and lower valley of the upper reach is in the other group.

The results (see Table 9-6, Figure 9-4) show that in the lower reaches, Changle City and Liangjiang County have high population pressure and a lack of forest resources, resulting in a lower sustainability rating. The middle reach is transitional between the mountain area and the plains and, because of the changes in landforms, it is very vulnerable. The headwater is less developed because it contains remote areas that lack infrastructure. Zhenghe and Ninhua counties are amongst the most eroded in the province. The lower valley benefits from the east coast economic development and from the forest resources derived from the middle reach and headwater; the sustainability indices are therefore the highest in the watershed. Overall the watershed ecosystem and economic development are facing serious problems.

Figure 9-4. The watershed classification.

Table 9-5. Indicators and weights.

Precipitation	Dryness index	Forest cover	Arable land per capita	Eroded modulus	GDP per capita	Income per capita	Industrial GDP	Illiteracy %	Engel's index
0.1	0.1	0.15	0.10	0.15	0.05	0.05	0.10	0.10	0.10

Table 9-6. The index of comprehensive development by locations.

	Upper reach								Middle reach	Lower reach	
	Headwater		Middle valley				Lower valley				
County	Zhenghe	Ninhua	Guangze	Jiangle	Puchen	Qinliu	Jianyang	Wuyishan	Minqin	Changle	Liang jiang
Score	0.45	0.47	0.51	0.53	0.54	0.55	0.61	0.62	0.48	0.46	0.5
Grouping	-1.23	-0.88	-0.18	0.18	0.35	0.53	1.58	1.75	-0.70	-1.05	-0.35

Mean value= 0.52, and standard deviation = 0.0571

(*The reason why Wuyi Shan City has the highest value in the watershed is that the city benefits from its unique nature beauty and biodiversity. It has been listed as a World Natural Heritage and Culture Heritage site. Wuyi Mountain National Conservation Zone is one of the UNEP GEF projects, with 56,530 ha. of natural forest being protected.)

9.4.2 SFMCAS analysis

The favourable and unfavourable conditions for sustainable forest management are summarized in Table 9–7.

Table 9-7. Summary of the result of the auditing criteria and indicators.

Criteria	Favourable	Unfavourable	Unknown
Biodiversity	▪ Wildlife protection laws are very clear and well-enforced. ▪ A government agency for wildlife protection was established and mandated. ▪ There are more than 20 well-protected natural conservation zones for wildlife and natural landscapes in the watershed. ▪ Many actions have been taken to protect wildlife, such as annual “National Bird Week’ and National Wildlife Rescue Program.	▪ Loss of habitat because of natural forest harvesting and fragmentation ▪ More forest land converted to agriculture and plantations and in intensive use in terms of monoculture and chemical use. ▪ Herbs, insects and birds are widely collected for medicine. ▪ Human disturbances, including tourism and recreation, are increasing.	Lack of information for fish and aquatic wildlife
Forest security	▪ Provincial government issues an AAC determination every five years and has strong control of the AAC ▪ The forest law enforcement system is well-established, and includes forest police, security, and forestry courts.	▪ There is still 15% of land with no title. ▪ Illegal logging exceeds 25–30% of the annual yield. ▪ High tax rates posed on log harvesting create negative impacts on forest security. ▪ Harvestable resources are less than 10% of the total resources.	

Table 9-7 (Cont.). Summary of the result of the auditing criteria and indicators.

Criteria	Favourable	Unfavourable
Forest ecosystem health and condition	▪ Around 20% of forest is protected and this figure will increase to 30% by 2010. ▪ High elevation mountain tops closed to allow natural succession (no human activities). ▪ Wood inspection bureau plays a major role in protecting against disease and insects both within and outside the region.	▪ Multiple rotations of plantations decrease the productivity of the land and ecosystem richness. ▪ Large scale of insect attack (Pine Dendrolimus spp.) and disease outbreaks (pine needle speckle, *Lecanosticta acicola*) ▪ About 45% of the watershed forest is affected by acid rain and air pollution.
Soil and water	Government provides substantial support for soil and water conservation and several projects have been launched.	▪ Large increase of soil erosion due to large-scale clearcuts, site preparation, and cultivation. ▪ Increase of non-point-source pollution due to plantation fertilization and agricultural and fish farms. ▪ Plantations, tea and fruit orchards are main sources of soil erosion. ▪ Increase of natural disasters; since 1990, there have been five devastating floods (1992, 1994, 1996, 1997, 1998).
Forest management practices	▪ Increased demand for wood materials and finished products. ▪ Large amounts of hardwood imports from outside the watershed and softwood and value-added products exported. ▪ Well-developed resource inventory systems and a long-term management plan.	▪ Forest harvesting practices which remove all the forest and site burning practices with no consideration of the habitat. ▪ Lack of an annual management plan. ▪ Lack of public participation and involvement. ▪ Forest management planning is much profit driven. ▪ Lack of project monitoring and evaluation.

Table 9-7 (Cont.). Summary of the result of the auditing criteria and indicators.

Enabling conditions for forest management	The laws and regulation for forest resource management and protection at different levels have been improving over time. Government invites the public to participate in key project decision making processes and monitoring. More than 10 government agencies have been involved in the watershed management.	Competing land use through stakeholders. Lack of interagency collaboration. Lack of collaboration between upper and lower reaches. Law enforcement is very difficult due to vagueness. Laws, policies and regulations lack specific detail on how to achieve sustainable development. Lack of trained professional and technical personnel at the county and town level to perform and support management, implementation, research and extension. Lack of public education and participation in planning, decision making, data collection, monitoring and assessment.

Summary of the integration assessments

Temporal integration. As a forest-dominated watershed, the assessment shows the impact of forest management on the sustainability of the watershed. From 1990–2001, forest management changed significantly due to the increased demand for wood products. Since 1990, more than 2000 wood manufacturing facilities have been established. Harvesting increased 20% from 1990 to 1995, and then dropped by 55% from 1996 to 2001 due to the depletion of harvestable forests. During this period, more than 50% of the total harvest came from natural forest, and more than 5% of forest land was converted to fruit, tea and other agriculture use. The watershed suffered devastating flooding in 1992, 1994, 1996, 1997, and 1998. The dam of Shuikou was completed in 1996, significantly changing the environment of the whole watershed.

Spatial integration. Table 9–8 provides a summary of the spatial differences of the various criteria when the two assessment techniques are integrated.

Table 9-8. Summary of the spatial differences of the various criteria.

Criteria	Headwater of upper reaches	Middle and lower valley of upper reaches	Middle and lower reaches
Economic development	**Drivers** ▪ Forest & agriculture dependent, accounting for 80% of income. **Issues** ▪ Traditional clear-cutting and short-term, high-yield plantations have significantly decreased land productivity. ▪ Deficient public utilities, including electricity, transportation, water supply and communication networks.	**Drivers** ▪ Heavy industry and forest-related manufacturing. ▪ Products and raw material distribution. **Issues** ▪ The industry needs innovation to increase productivity and efficiency, especially for waste treatment.	**Drivers** ▪ Trade, financial and service. ▪ Well developed public service systems and business environments. **Issues** ▪ The cost of water, power and real estate are relatively high.
Social well-being	▪ Livelihoods depend on land management and production. ▪ Deficient social security system. ▪ Lack of social insurance support.	▪ Social security varies depending on the financial situation of particular industries. ▪ Salary depends on industry conditions. ▪ Increasing unemployment rate.	▪ Deficient social security, insurance relies on personal business. ▪ Livelihoods depend on general business and personal management.

Table 9–8. Summary of the spatial differences of the various criteria (Cont.)

Population pressure	▪ High population pressure in terms of low household annual income. ▪ Small proportion of well-educated people	High population pressure from increase of unemployment from state-owned enterprises.	▪ High population pressures based on the density. ▪ Large proportion of well-educated people.
Resource capacity	▪ The quality and quantity of harvestable forest is only 10%, 15% of the total watershed ▪ Current 30% of the forest will be either protected or conserved ▪ Increased use of chemicals.	▪ Greatly decreased area of arable land. ▪ The supply of raw materials is declining.	▪ Shortages of water and electricity supply. ▪ Most natural resources exhausted.
Environmental constraint	▪ Increase of soil erosion and landslides. ▪ Soil contamination.	▪ Increase of vulnerability to natural disasters. ▪ Water and air pollution ▪ River sedimentation.	▪ Water supply shortage. ▪ Waste water and air pollution.

9.5 DISCUSSION

The Min River Watershed used to have abundant natural resources, especially in the upper reaches of the watershed, which is one of the most outstanding subtropical forests in the world (UNESCO, 1999). Due to the long period of over-exploitation, especially in recent years, an increase in the watershed's vulnerability has occurred, resulting in a low sustainability rating. Practices such as over-cutting of natural forests, intensive land use for agriculture and plantations, widespread use of chemicals, and the increase of industry, population, and urban sprawl, are the main drivers causing degradation of the watershed (e.g., Zhang *et al*., 2000, Fujian Chorography Compilation Committee, 2002; Zeng *et al*., 2003).

9.5.1 Land-use competition

As a result of the increase in the population and the corresponding economic growth, the native vegetation, comprising Subtropical Evergreen Broadleaf Forest, has been replaced by agricultural lands and plantations. The changes in land use, especially the depletion of nature forest cover, have reduced soil-water holding capacities. For instance, the water-holding capacity in a natural forest is approximately 130 mm m^{-2}, but in tea plantations and agricultural land, it is only about 26.6 mm m^{-2} (e.g., Zhang *et al*., 2000; Huang *et al*., 2005; Zhu and Cai, 2007). Improper management of the forests in the watershed has resulted in the degradation of these ecosystems, with forest land erosion now comprising 67% of the total eroded area (e.g., Chen, 2000). Improper forest management can be seen as a major barrier if sustainable development is to occur in the upper reach of the watershed.

9.5.2 Different processes and priorities

The regional relief geographically divides the watershed into three geographical regions. The upper reaches consist of mountainous areas (headwater, middle and lower valleys), with an abundance of natural resources and minimal infrastructure and public service networks. However, traditional land management practices have caused soil erosion, loss of biodiversity and reduced land productivity (Higgiti and Rowan, 1994; Huang et al, 2000). The middle and lower valley areas of the upper reach have benefited from economic development and traditional industries along the coast, and economic development is occurring rapidly. Industrial pollution and the layout of the cities in the lower valley are major issues and are impacting their development (e.g., Zhang et al., 2004).

The middle reach was strongly affected by the morphology of the land and the Shuikou dam project, and the ecosystems have become extremely vulnerable (Hu S.L. and Chen, Z, Q. 2006). The lower reaches of the watershed consist of low-lying, flat land. This area has a well-developed social and economic system. The main barriers faced in this area are the high density of the population and the lack of natural resources (Zhang et al., 2004). The annual rainfall pattern is also exacerbating the fragility of the watershed. The "Plum rains" occur from March to June accounting for 50–60% of precipitation and the typhoon rains occur from July to September, accounting for 20–40% of precipitation. The rain events occur in short time periods in the spring or summer; causing large amounts of soil erosion and many landslides (Huang et al, 2000 and Wang et al., 2009).

9.5.3 Increasing pollution levels

Since economic development began, manufacturing industries have increased by more than 40% through the establishment of new facilities and through established facilities increasing their capacity. Annually around 34.5 million tonnes of waste water from 1135 mills drains into the Min River (e.g., Zhu, 2005). In addition, more than 45% of the forest and agricultural land and 60% of cities are affected by acidic deposition and other forms of air pollution. The increase in the use of fertilizers, pesticides, and herbicides in the watershed has increased the non-point source pollution to the watershed. The use of fertilizers has increased 48.5% since 1990 (e.g., Chen, 2000). Water lettuce is an example of a watershed problem that has rapidly spread throughout the watershed, creating numerous problems.

9.5.4 Urban sprawl and infrastructure construction

Despite the competition between rural land use and urban sprawl and infrastructure construction, there has been an expansion in the urban space and public service system, especially through road network construction, water supply and sewage systems, and power systems. The increase in infrastructure has increased sedimentation in the watershed. Since 1990, many cities including Jiangou, Jiangyang, Sanming and Shaxian have expanded along the banks of the Min River tributaries. Currently, approximately five million people live around the confluence of the three main tributaries. Increasingly, these areas have become susceptible to natural disasters and pollution due to unsustainable land management in the watershed (Zeng *et al.*, 2003; Song and Cai, 2005). In particular, the development of the Shuikou Hydroelectric Dam has increased the water level and slowed the flow in these municipal areas.

9.5.5 Population patterns

Accompanying the economic development and government policy, there are two types of population concentrations. One is in traditional forest areas, where poor and uneducated people rely on natural resources. Since intensive farming and harvesting began, these areas have become the most vulnerable regions. Today, local people want to have better lives with improved roads, housing, drinking water, electricity, and communication. To achieve these services they have to increase logging volumes, causing ecosystem destruction. Additionally, construction of these services has become a huge source of soil erosion (Wang et al., 2009). The other population concentration is in the valley. Recently, this population concentration has begun radiating out from the east coastline. This has caused an economic boom, and improvement to the infrastructure network of the watershed. The urbanisation of the watershed has potentially exceeded the natural carrying capacity of the watershed. One of the reasons why the flooding in 1992, 1994, 1996, 1997, and 1998 became the most devastating in the history of the watershed was because of the improper urban sprawl and population concentration within the watershed (Lou and Le, 1996; Fujian Chorography Compilation Committee, 2002; Song and Cai, 2005).

9.6 CONCLUSIONS

This study has integrated two assessment approaches for evaluating watershed sustainable management from spatial and temporal dimensions and strategic and tactical levels. However, there is still much room for improvement. For instance, the criteria and indicators for temporal and spatial assessments in RSDA should be the same. The differences in political and geographic boundaries still problems for data collection and comparison.

The results of RSDA analysis suggest that the watershed has a low rating for sustainable development. Spatially, the uneven sustainability in different parts of the watershed reflected the combination of biophysical, economic, social, political, and institutional factors. Over the last decade, the sustainability rating of the watershed has improved; although at a very low rate. The analysis also identified that the degree of environment and resources constraint index is higher than the degree of the development; this indicates that there is potential for sustainable development. The resource carrying capacity and population distribution pattern should have been considered in development and should be considered in the watershed strategic planning. The SFMAS examines the mechanism of the sustainable development, and interaction between biophysical, economic, social, political, and institutional factors. The results show that conventional practices, population increases, competition for land and water resources, and misuse of these resources have resulted in significant watershed pollution, sedimentation, landslides, flooding, drought, and soil erosion.

The government has recently taken some serious steps to reduce the negative impact on development in the watershed. However, systematic and fundamental changes are still required for future development in the watershed to be truly sustainable.

9.7 REFERENCES

Appanah, S. and Kleine, M. 2001. *Auditing of sustainable forest management*. Forestry research support program for Asia and the Pacific (FORSPA). Food and Agriculture Organization of the United Nations, Bangkok.

Cai, D.Z. and Cai, S.S. 2005. *Historical record of China meteorological disasters – Fujian Volume*. Meteorological Publishing House: Beijing

Chen, C.M. 2000. Course analysis and counter-measures of ecological and environmental problems in Min River Basin. *Journal of Geography in Taiwan Strait* 19(2): 237–243.

Chen, Q.Y. and Song, Y.X. 2004. Study and assessment of the sustainable development of Northeast China. *Journal of China Population, Resources and Environment*. 14 (1): 78–83.

Chen Y., Chen J.F. and Chen Z.Q. 2006. Comparative analysis of land use change between upstream and downstream counties of the Min River Watershed. *Soils*. 38 (1): 48–52.

Dalkey D.C. 1969. *The Delphi method: An experimental study of group opinion*. Rand Corporation. http://www.rand.org/pubs/research_memoranda/RM5888/

Davenport, T.E. 2003. *Watershed project management guide*. Lewis Publishers: Boca Raton.

Duan, Y., Zhang, Y.Z., Li, Y.F. and Niu, Z.Y. 2007. Pollution load and environmental risk assessment of livestock manure in the Minjiang River Valley. *Journal of Ecology and Rural Environment* 23(3): 55–59.

Ffolliott, P.F. Baker, M. B., Jr., Edminster, C. B., Dillon, M. C., Mora, K. L.2002. *Land stewardship through watershed management: perspectives for the 21st century*. Springer: New York.

Fujian Chorography Compilation Committee 2002. *Fujian chorography*. Fuzhou, Fangzi Publishing.

Fujian Environmental Protection Agency 2003. *Fujian environmental status annual report*. Fujian Environmental Protection Agency, Fuzhou.

Fujian Environmental Protection Agency 2006. *Fujian environmental status report*. http://www.fjepb.gov.cn/common/FJview.aspx?mid=121&id=185&back=1

Fujian Statistical Bureau 1991–2003. *Fujian statistical yearbook.* China Statistical Press: Beijing.

Fujian Statistical Bureau 2002. *Fujian statistical yearbook*. China Statistics Publishing House: Beijing.

Fujian Statistical Bureau 2007. *Fujian statistical yearbook*. Beijing Statistical Publishing House: Beijing.

Higgiti, D.L. and Rowan, J.S. 1996. Erosion assessment and administration in subtropical China: a case study from Fujian Province. *Land Degradation and Development* 7: 1–10.

Hong, W. 2002. *The Min River watershed forest ecosystem research.* Xiamen University Press: Xiamen.

Hu S.L. and Chen, Z, Q. 2006. Changes of the main land use types in Minjiang watershed and their effects. *Fujian Geography 20 (2):15-18,9.*

Huang, R.Z., Yang, Y.S. and Zhang, J.C. 2005. Change of soil reservoir storage in different forest land types. *Bulletin of Water and Soil Conservation* 25(3): 1–5.

Huang, Y.H., Lin, J.L., Cai, Z.F., Chen, M.H. and Zhou, F.J. 2000. Major influential factors of soil erosion in Fujian Province. *Journal of Soil and Water Conservation* 14(2): 36–40.

Jia, R.X. and Liu, Y. 2003. China's regional sustainable development status quo and its classification. *Journal of Geographical Research* 22(5): 609–617.

Kasemir, B., van Asselt, M.B.A., Durrenberger, G.. and Jaeger, C.C. 1999. Integrated assessment of sustainable development: multiple perspectives in interaction. *International Journal of Environment and Pollution* 11(4): 407–425.

Li, Z.Y., Wang, J.Y., Xiong, J.Q. and Xu, T.T. 2007. *Models and applications of sustainable development assessment.* Science Press: Beijing.

Lin, K.M., Hong, W., Yu, X.T. and He, Z.Y. 2001.The effect of tending methods on growth and population structure of young Chinese fir plantation. *Scientia Silvae Sinivcae* 37(6): 26–33.

Liu, Q.S. and Shen, H. 1997. Study on index system and assessment approach for regional sustainable development. *China Population, Resources and Environment* 7(4): 60–64.

Long, A. 2006. Auditing for sustainable forest management: the role of science. *Columbia Journal of Environmental Law* 31: 1–44.

Lou, C.Z. and Le, J.X. 1996. *China biggest flooding – Damaging flooding in the history.* China Bookstore: Beijing.

Neumayer, E. 2001. The human development index and sustainability – a constructive proposal. *Ecological Economics* 39(1): 101–114.

Purohit, B.C. 2005. Introduction to indices of human development. USAID Reform Project. Presentation in November 2005. http://www.authorstream.com/Presentation/Reginaldo-59852-Introduction-Indices-Human-Development-Measuring-quality-life-WORLD-2OO5The-Economist-to-Education-ppt-powerpoint/

Robert, K.H., Schmidt-Bleek, B., Aloisi de Larderel, J., Basile, G., Jansen, J.L., Kuehr, R., Price Thomas, P., Suzuki, M., Hawken, P. and Wackernagel, M. 2002. *Strategic sustainable development – selection, design and synergies of applied tools.* Journal of Cleaner Production 10 (3), 197–214.

Saaty, T.L. 2000. *Fundamentals of decision making and priority theory with the Analytic Hierarchy Proces*s. Volume 6. RWS Publications: Pittsburgh, PA.

Segnestam, L. 2002. *Indications of Environment and Sustainable Development: Theories and Practical Experience.* The World Bank Environment Department. pp.61.

Sarageldin, I. 1996. *Sustainability and the Wealth of Nations: first steps in an ongoing journey.* Environmentally Sustainable Development Studies and Monographs Series No. 5. The World Bank, Washington, D.C.

Sustainable Development Research Group of China Academy of Science 1999. *Strategic report on China sustainable development*. Science Press: Beijing.

Sustainable Development Research Group of Chinese Academy of Science 2000. *Strategic report on China sustainable development*. Science Press: Beijing.

Sustainable Development Research Group of Chinese Academy of Science 2001. *Strategic report on China sustainable development*. Science Press: Beijing.

Sustainable Development Research Group of Chinese Academy of Science 2002. *Strategic report on China sustainable development*. Science Press: Beijing.

Sustainable Development Research Group of Chinese Academy of Science 2003. *Strategic* *report on China sustainable development*. Science Press: Beijing.

UN Commission on Sustainable Development 1996. *Indicators of sustainable development: Framework and methodologies*. New York: UN

United Nations Development Programme 1999. *Human development report*. Oxford University Press, Oxford.

UNESCO 1999. Mount Wuyi. http://whc.unesco.org/en/list/911/

Wang, G.Y. 1991. *Guideline for Fujian state-owned tree farms forestry management classification*. Fujian Department of Forestry, Fuzhou, China.

Wang, G.Y. and Yang, Y. 2001. Study on development strategies for Fujian forestry management and forest industry. *Journal of Forestry Survey and Design* 1: 1–9.

Wang, G., Innes, J.L., Yang, Y., Chen, S., Xie, J. and Lin, W. 2009. Extent of soil erosion associated with large-scale infrastructure development and possible amelioration measures. *Catena*, accepted, subject to revision.

Wang, J.Y. and Zhu, X.D. 2007. The health of watershed and soil conservation. *Hydraulics Science and Technology* 4: 61–63.

Yang, D.P. 2008. *The green book of the environment: Crisis and turning of China's environment.* Social Sciences Academic Press: Beijing.

Yang, Y. and Wang, G.Y. 2001. Study on sustainable management criteria and indicators in Southern China. *Journal of Forestry Survey and Design* 2: 34–40.

You, X.W. 2006. The exploration, utilization and protection of the Min River Watershed. *Subtropical Soil and Water Conservation* 18(3): 89–91.

Yu, X.T. 1999. One the regression of Chinese fir plantation: discussion on the sustainable management of Chinese fir in terms of the cause and effect of soil degradation. *World Forest Research* 12 (5), 15–19. (in Chinese).

Zeng, C.S., Tang, X.H. and Wang, J.K. 2003. *The investigation report on Status Quo of Fujian's ecological environment.* China Environmental Science Press: Beijing.

Zhang, C.X., Yang, Y. S., Liao, F.L. 2004. *The Min River Watershed Ecology and Social Economic Development.* China Forestry Publishing House: Beijing. pp

Zhang, G. F., Chen, R.Y., Zen, J.R. and Lin, W.G. 2000. A study on flood and fragility of environment in Min Valley. *Bulletin of Soil and Water Conservation* 20(4): 51–55.

Zheng, D.X. 1999. Some thoughts and suggestions of the comprehensive measurement on the Min River Watershed Development. *Hydraulics Science and Technology*. Sp. 15–17.

Zhu, W.-R. 2001. *The evolution of forest resources in Fujian through the ages*. Master Thesis. Fujian Normal University.

Zhu, X.D. 2005. Water pollution control in the Min River Watershed. *Subtropical Soil and Water Conservation* 17 (4): 56–57.

Zhu, X.D. and Cai, G.L. 2007. Water and soil erosion and ecological security. *Subtropical Soil and Water Conservation* 19(1): 10–12, 23.

10 CONCLUSIONS

China is in a period of social, economic and political transition. China's watershed management policy and its forest tenure and related policy reforms have undergone remarkable changes since the devastating floods of 1998. The government has launched a series of key national programs and forest policy reforms. The scale and investment of these forestry programs are already producing some tangible benefits to forest cover, the wood industry and rural livelihoods. Large areas are protected from logging and huge afforestation programs are underway, around 5 million ha. of natural forest have been protected, 8 million ha. of agricultural land has been converted back to forest, 5.6 million ha. of forest in the Yangtze River watershed and 3.5 million ha. in the Zhu River watershed has been established since 1998 (SFA, 2008), and ongoing privatization offers the hope of more efficient and effective operations that can create jobs and stimulate economic growth.

China has invested 20 billion Yuan in solving drinking water problems for 60 million rural residences in the period 2000–2005, 160 billion Yuan in constructing comprehensive flooding control systems in the Yangtze River in the period 1998–2005, 150,000 point sources of pollution have been closed, and 110 billion Yuan have been used to address soil erosion (Jiao, 2006). Several laws has been passed since 1998, including a new Water Law, Flood Protection Law, Water Pollution Control Law, and Law for Soil and Water Conservation, as well as numerous bye-laws promulgated by regional and local government. Successful water and watershed protection is enabling China to support 22% of the world's population with only 6.8% of the world's arable land and 6% of the world's water resources (Jiao, 2006).

However, due to the uneven distribution of water in the country, its huge population and the continuous rapid economic development, the pressure on water resources and watershed environments is enormous. Several key issues have hindered social, economic and environmental development nationwide. Jiao (2006) has pointed out that the floods in southern China have resulted in average losses of more than 110 billion Yuan (1% of GDP) since 1990, and runoff has decreased almost 10% over the last 20 years in the Yellow, Huai, Hai, and Liao River watersheds. Drought is a major issue in northern China; untreated industrial waste and urban waste discharges into water bodies have aggravated water shortages and pollution; and over-exploitation of natural resources, such as forest and ground water, together with a lack of proper protection, have led to widespread ecosystem degradation.

10.1 SUMMARY RESULTS

China has emerged as a major power in the world's wood market in terms of importing raw materials and exporting processed wood. Its success has raised serious concerns about the depletion of natural resources and the global environmental impacts of the increased demand for wood. China has responded with major forestry reforms, such as large-scale plantation development, logging bans in natural forests, land-use reforms, and reforestation initiatives. Despite these efforts, the transition of China's forestry sector to a sustainable operation remains in doubt. The research presented here suggests that there are five issues challenging the future development of China's forestry sector: (1) China's unsustainable appetite for wood; (2) the increasing environmental burden; (3) a plantation program that is only a temporary solution to the problem of wood shortages; (4) the impact of forestry on China's most vulnerable—the rural poor; and (5) the ongoing forest land ownership reforms aimed at solving China's demand for wood and restore environment are in question.

Over the past two decades, China has successfully established millions of hectares of bamboo forest, which has restored fragile ecosystems, provided benefits to local communities, alleviated poverty and eased timber shortages. Bamboo forests, due to their special characteristics and ecological functions, play an important role in sustainable forest management and rural development in China. However there is potential for further improvements to the bamboo forest estate. The main issues relate to governance systems, local economic development and traditional management practices.

Forestry and forest management were for a long time viewed as contributing to environmental protection. However, forestry can contribute both positively and negatively to flooding. Sustainable forest management and natural forest protection are vitally important to forest dependent communities in forest-dominated watersheds such as that of the Min River.

Watershed issues are complex and multidimensional. Improved forest management can only be a partial solution. Rapid economic development in China has resulted in land-use change and pressures on the natural resources of watersheds. Massive infrastructure development has altered landforms, vegetation and waterways, and has led to water and soil erosion and land degradation. In the Min River Watershed, infrastructure development has become the largest human-induced disturbance of the land in the watershed's history. A simulation experiment measured soil erosion across different land covers for a period of one year. The results indicated that exposed soils without grass generated soil and runoff that were 3 times and 1.7 times greater, respectively, than natural barren land. Two periods were particularly important: March to June and July to September, with 42.9% and 55.3%, respectively, of the annual soil erosion. This corresponds with the annual wet season associated with the Asian monsoon and summer typhoons. Timing construction properly and the immediate reseeding of exposed soils could reduce soil erosion by a factor of 9.3. These results could be used to aid the development of sound management practices to control soil and water loss in the subtropical red soil area of southeast China.

While the scale of the watershed is too big to use traditional ground-based surveys, remote sensing data and GIS computer tools such as Arc/info, PCI as ERDAS are useful for assessing land-use changes in the watershed. The research used Landsat imagery from 1986, 1990, 2000 and 2003 to detect the pattern of change in land-use for the Min River Watershed. There have been major changes in the land-use of the Min Watershed over the last two decades due to the aggressive economic development policy and population growth in the watershed. The increasingly intensive land use and over-exploitation has resulted in a number of potentially adverse trends, such as urban expansion onto the regulated flood plain, construction that has altered the river channel, depletion of natural forest and grassland, and an increase in the area of plantations and orchards. Rapid action is needed to ensure that future development moves towards more sustainable forms of land management.

Local knowledge of watershed protection is important. In this research, the results were directly or indirectly verified by previous research, including that on watershed land-use changes, and forest practices and their impacts on watershed health. Public awareness about the needs for environmental protection is high, and there is a clear public wish for sustainable development in the watershed. Public awareness of watershed issues includes watershed pollution, flooding, drought, soil erosion and *Pistia stratiotes* outbreaks. Over-logging of natural forests, discharge of untreated waste directly into water bodies, and improper forest and agricultural practices are considered to be the main contributors to the environmental problems present in the watershed. There is a willingness amongst the public to participate in the development of the watershed, which extends a willingness to contribute financially to watershed environmental protection and to participate in watershed activities.

Questionnaire and interview analysis are key techniques for the analysis of complex issues such as watershed issues that involve large-scale social, economic and environmental problems. The approach enables a clear understanding of the main concerns amongst the public, which in turn enables policy makers to address the key issues. It is also prudent to make full use of local knowledge in any decision-making process.

10.2 FUTURE MANAGEMENT STRATEGIES IN THE WATERSHED

Future management of the Min River Watershed will focus on the following four aspects:

1) Holistic watershed management. Watershed management is no longer viewed as single- or dual-purpose management. It will be undertaken as a single holistic system where social, cultural, economic and environmental management needs interact with each other. The use of systems engineering approaches and systems dynamics techniques will help diagnose the major issues, and will enable the careful planning and implementation of watershed projects.

2) Integrated, up-to-date science and technologies. The development of computer science, geo-spatial technologies, simulation modeling techniques and optimized decision-making approaches will allow watershed managers to bring together personnel from diverse disciplines, to integrate data from multiple dimensions and to develop a comprehensive management tool that will enable managers, stakeholders and third party interest groups to work together effectively in solving watershed management problems.

3) Innovated watershed management legal systems and institutional structures. A comprehensive law to promote the development of watershed management will be established; this will require cooperation between jurisdictions, inter-governmental agencies, and upland and downstream groups. The new coordinated organizations for watershed (basin) management will be established as the Fujian Provincial government planned in 2008 to exercise the duty to facilitate, implement and monitor watershed development.

4) Widely expand public participation. The success of watershed management will largely depend on the degree of public input, the contribution of local knowledge and the establishment of a democratic decision-making process. Continuous improvement of the awareness of all stakeholders about the importance of sustainability will be needed.

10.3 FUTURE RESEARCH

The research presented here is one third of the project “Study of Sustainable Management in the

Min River Watershed". The parts of the study were led by Professor Hong (watershed inventory and environmental assessment) and Dr. Ye (watershed social impact assessment and the best management plan). Due to time limitations associated with the current project, a considerable amount of research is still needed.

Firstly, this work has been placed into a broader context by examining current forest policies and their relation to environmental protection programs in China. Particular emphasis has been placed on the evaluation of forest policy and national programs to combat flooding. The work has not been placed within the even broader context of international forest and watershed development policies: this would have constituted a thesis in itself.

Secondly, I initially planned to develop a watershed simulation model that could aid managers in deciding how best to manage the factors impacting this sensitive area. I have tried to use watershed social, economic and environmental data and use Stella 7.03 (ISEE Systems, 2005) to simulate the different scenarios of management trajectories. However, I was unable to verify the system. The model seems very sensitive to changes in land use and too slow in its response to major investments. I believe that the model could be operationalized with sufficient time.

Thirdly, there is a need to develop a new watershed forest management approach by integrating sustainable forest management and sustainable watershed management. Watershed forest management approaches need to be based on the integration of watershed classification, assessment approaches, sustainable forest management C&I and modeling techniques. Watershed forest management approaches need to move from a focus on forest resource management to develop a regional sustainability that includes the social eco-economy, social culture, regional legislation, regulation, codes and the overall well-being of communities.

Fourthly, watershed pollution needs to be examined in greater detail and more systematically, including both water and air pollution. The impacts of both on the ecosystems of the watershed are largely unknown.

Fifthly, the questionnaire on social attitudes towards development generated very large volumes of data, not all of which has been analyzed here. Further analyses are needed of these data, particularly in relation to gender, spatial differences in the responses, the role of education and other factors.

Sixthly, the research only examined land-use changes in the watershed. A more detailed examination of changes between the reaches and in the economic development zones over the last twenty years are called for, and would reveal how the level of economic development can affect land-use.

Ultimately, the research should be integrated with spatial data, regional socio-economic data and the criteria and indicators of sustainable management using a holistic systems dynamic model that will aid decision support in management.

10.4 REFERENCES

Jiao, Y. 2006. Keynote speech at 12th World Water Congress on Nov 22–25, 2005. New Delhi. China Ministry of Water Resources.

SFA 2008. *The 2007 China forestry development report*. China State Forestry Administration.

ISEE Systems 2005. Stella Simulation Software. High Performance Systems, Inc. www.iseesystems.com.

APPENDIX I. MAIL SURVEY RESEARCH QUESTIONNAIRE

Note: This questionnaire was originally written in Chinese. It has been translated for the benefit of the Ethics Review process; the translation is literal, and may therefore seem a little odd in places where there is no direct equivalency between Chinese and English terms.

THE SOCIAL CONCEPTION AND IMPACTS OF WATERSHED MANAGEMENT IN THE MIN RIVER BASIN, CHINA

I would like to take this opportunity to thank you for your willingness to participate in this study. I wish to remind you that your identity will remain completely confidential, and the answers you provide will remain anonymous. If you feel uncomfortable with any question you need not answer it. Your participation is purely voluntary and your consent to participate in this research is indicated by completing and returning the questionnaire.

A report summarizing the results will be presented to the Fujian Provincial government for watershed management research purposes and the study will also generate a PhD dissertation at the University of British Columbia. The report will contain summary statistics but the results will be presented in a manner that will enable identification of individual participants.

The results of the questionnaire will be collected by the Fujian Provincial Forestry Department and passed to Dr. John Innes and Mr. Wang Guangyu of the Faculty of Forestry, University of British Columbia, Canada, for analysis. No others will have access to the information in its unprocessed form.

Instructions

PLEASE DO NOT WRITE YOUR NAME ON THIS QUESTIONNAIRE.

1. This questionnaire is not designed to be a test of your knowledge, but rather to provide important scientific information. To ensure the quality of the results, I urge you to answer the questions as completely as possible. If you want to add more information about any question please feel free to do so. Many of the questions require you to place a check mark or circle letter (or number) beside the applicable response category. Some questions require that you answer yes or no. For these questions simply circle Yes or NO.

2. The questionnaire is printed on BOTH sides of the paper – please be careful not to skip any pages.

3. When you have completed the questionnaire, please return it in the large self-addressed business reply envelope. You do not need to attach postage.

4. If you have any problems, questions, or comments, please call Mr. Wang Guangyu at the following telephone number: 13328253666.

Questionnaire

Section I. Questions about you

1. In which city (county), town and village do you live?
   ____

2. What is your gender?

   A. Male
   B. Female

3. Which age group are you in?

A. 12–18   B. 19–29   C. 30–39   D. 40–49
D. 50–59   F. 60–69   E. 70–79

4. Are you married?

   C. Single
   D. About to marry
   E. Married without child
   F. Married with child
   G. Divorced
   H. Widowed

5. What is the highest level of education you have received?

   A. Primary school
   B. Junior school
   C. High school
   D. Received a college or technical school certificate
      Please specify major or subject: __________________________________
   E. Received a university bachelor's degree
      Please specify major or subject: __________________________________
   F. some postgraduate training
      Please specify discipline: ______________________________________
   G. Received a postgraduate university degree
      Please specify type of degree and discipline:________________________
   H. other (please state) ____

6. What is your annual income group?

   A. <1, 2000
   B. 12,000–24,000
   C. 24,000–36,000
   D. 36,000–60,000
   E. 60,000–120,000

F. >120,000

7. Do you work for:

A. a government department or ministry
B. a large company
C. a small business
D. an institution
E. yourself
F. other (please provide a brief description below)

____

8. What industry do you work in?

____

9. Which category best identifies your career?

A. Government officer
B. Business person
C. Industrial worker
D. Social worker

The questions from #10 to # 15 are about your understanding of watersheds.

10. Do you know what a watershed is?

A. Yes (please go to #11)
B. No (please go to #12)

11. A watershed is the specific land area that drains water into a river system or other body of water. Which of the following statements do you think is/are true about watersheds?

A. Watersheds are the primary source of unprocessed water.
B. Watersheds provide other goods, such as timber, fish, and agricultural products.
C. Watersheds provide other services such as hydroelectric power, biodiversity conservation, recreation, and carbon sequestration.
D. A good forest cover enhances the way watersheds provide these various goods and services.

12. A watershed is the specific land area that drains water into a river system or other body of water. Can you say what the Min River Watershed is?

____

13. How long have you lived in the Min River Basin?

A. Never left the watershed
B. More than 20 Years

C. More than 10 years
D. More than 5 years
E. More than 1 Year
F. Less than 1 year

14. Do you work in a job related to watershed management?

A. Yes
B. No

If yes, please describe your job ________________________

15. Which of the following statements best describes your position on environmental issues?

A. Environmental protection should have top priority
B. Development of the economy should have top priority
C. Economic development and environmental development should proceed simultaneously and with equal priority

Section II. Questions about the watershed issues

1. What do you think about the current environmental situation in the Min River watershed?

   A. Major and very serious problems
   B. Many problems
   C. Few problems
   D. No problem at all
   E. I don't know

2. In the last thirty years, has the condition of the watershed changed?

   A. Great improvement
   B. Some improvement
   C. No change
   D. Some worsening
   E. Major worsening

3. Ho do you think the following indicators have changed over the last thirty years?

Indicator	Great increase	Small increase	No change	Small Decrease	Great Decrease
Water quality					
Water quantity					
People swimming in the river					
Drinkable water					
Fish population					
Navigation					
Polluted water					
River sedimentation					
Cut off days					
Flooding days					
Overall situation					

4. What concerns you the most in the watershed?

   A. Flooding
   B. Drought
   C. Pollution
   D. Drinking water
   E. River transportation
   F. Wildlife
   G. Land productivity
   H. All above

5. What is most serious disaster that has happened in the past?

   A. Flooding
   B. Landslide
   C. Water pollution
   D. Forest fire
   E. Drought
   F. Alien plants (水葫芦) *Eichhornia crassipes*

6. Please mark which of the following factors you think have contributed to watershed disasters? (If you think something is not a factor, please mark ｘ; if you think that it is a factor, please mark √, and then give a weight which you think it is appropriate (5 is greatest, 1 is least).

Factor	√（yes）／ｘ （no）	Score (1–5)
Clear-cutting of forests		
Misuse of agriculture land		
Dam building		
Fish farms in the river		
Animal farming along the river		
Untreated waster water from industry		
Over use of water resource		
Waterway damage or construction		
Dumping wastes into the river		
Urban expansion and population pressures		
Road system development		
All the above		

7. What kind of natural disasters do you think may happen in the near future?

   A. Flooding
   B. Landslide
   C. Drought
   D. Water pollution
   E. Forest fire
   F. Alien plants

8. In your opinion, what are the most important environmental problems facing the watershed?

---

9. The following questions are designed to obtain your opinion about the environmental quality of the watershed. For the following statements, indicate whether you believe the issue is very serious, somewhat serious, not serious, irrelevant, or have no opinion. (Please place a check mark in the column that best expresses your opinion.)

	Very Serious	Somewhat Serious	Not Serious	Irrelevant	No Opinion
How serious a problem do you feel water pollution is in the watershed?					
How serious a problem do you feel air pollution is in the watershed?					
How serious a problem do you feel liquid waste disposal (i.e. sewage) is in the watershed?					
How serious a problem do you feel that solid waste disposal is in the watershed (e.g., using land fills to dispose of solid waste)?					

10. How do you think the overall condition in the watershed will be in the future?

☐ Very good ☐ good ☐ no change ☐ bad ☐ worst

11. Are there any significant climate changes in the watershed?

☐ Significant change in____________
☐ Little change in_______________
☐ No change

12. Do you think watershed managers should be taking actions in response to climate change?

☐ yes ☐ no ☐ not sure

Please elaborate on your answer.

____

____

Section III Questions about watershed management in the Min River

1. How significant is the Min River watershed to Fujian's social economic and environmental development?

☐ Very important ☐ important ☐ not at all

2. How important is the watershed for the following industries?

	very important	Important	not important
Forestry			
Agriculture			
Industry			
Hydropower			
Fishery			
Transportation			
Recreation and tourism			
Wildlife			
Irrigation			
Drinking water system			

3. Good watershed management is important to:

A Local people
B Industry
C Community
D Business
E Government
F All of the above

4. The following questions were designed to obtain your opinion regarding the environmental quality of the watershed. Please indicate your level of agreement with the following statements. (Please place a check mark under the column that best expresses your opinion.)

	Completely Agree	Mostly Agree	Partly Agree/ Disagree	Mostly Disagree	Completely Disagree
We should relax our efforts to control the watershed's environment in order to improve the economy.					
There has been too much emphasis on conserving natural resources and not enough on using them.					
Environmental protection measures have created an unfair burden on industry.					
Where natural resources are privately owned, society should have no control over them.					
We should maintain our efforts to protect the watershed from environmental pollution, even if this slows down the economy and increases unemployment.					
If an industry cannot control its pollution, the industry should be shut down.					
There should be penalties for the managers and owners of polluting industries.					
Natural resources should be preserved for the future, even if people must do without.					

5. Which of the following measures do you think are necessary to maintain the health of the watershed?

1). Husbandry farming

	Completely Agree	Mostly Agree	Partly Agree/ Disagree	Mostly Disagree	Completely Disagree
Government should be responsible for the overall planning of development of livestock husbandry in the watershed					
Encourage full utilization of excrement.					
Encourage dimensional development					

2) Urban waste treatment

	Completely Agree	Mostly Agree	Partly Agree/ Disagree	Mostly Disagree	Completely Disagree
Encourage a recycling industry					
Make residential developments recycle their wastes					
Require the development of urban waste treatment plants					
Develop urban sewage systems					

3) Drinking water systems

	Completely Agree	Mostly Agree	Partly Agree/ Disagree	Mostly Disagree	Completely Disagree
Protect the sources of drinking water					
Encourage water saving programs					
Provide incentives to conserve water					

4) Industry pollution control

	Completely Agree	Mostly Agree	Partly Agree/ Disagree	Mostly Disagree	Completely Disagree
Prevent polluted water from draining into the river					
Set an emissions quota for each industry					
Develop incentives for pollution control					

5) Restoration of the watershed

	Completely Agree	Mostly Agree	Partly Agree/ Disagree	Mostly Disagree	Completely Disagree
Remove dams in critical areas					
Clear alien invasive plants					
Prohibit mining along the river					
Return agricultural land to forest					
Prevent illegal use of waterway					

6) Forest practices

	Completely Agree	Mostly Agree	Partly Agree/ Disagree	Mostly Disagree	Completely Disagree
Ban the logging of natural forests					
Increase the size and number of natural reserves					
Ban the logging of forests along the rivers					
Ban the clear-cutting of forests					
Ban the use of soil turn-over practices					
Control the scale of cutting in plantations and leave habitat for wildlife					

7). Support systems development

	Completely Agree	Mostly Agree	Partly Agree/ Disagree	Mostly Disagree	Completely Disagree
Develop a legal framework for watershed protection and development					
Plan watershed management					
Development target responsibilities for local officers					
Enhance public education for watershed protection					
Develop public participatory systems					
Develop environmental monitoring systems					
Develop crisis response systems					
Develop interagency collaboration mechanisms					

Section IV Questions about forest management

1. Please indicate your level of satisfaction with the following aspects of forest management.

	Very Satisfied	Little Satisfied	Satisfied	Disappointed	Very disappointed
Silviculture practices					
Forest management					
Stand and species diversity					
Fertilization					
Wildlife protection					
Fire protection					
Logging practices					
Riparian protection					

2. Mainly, we regard the following practices as being poor forestry. Do these still happen in the watershed to some degree?

	Very often	Often	Sometimes	Very little	Not anymore
Burning slash and shrub					
Turn over preparation					
Large scale clear cutting					
Monoculture					
Logging without leaving a riparian zone					
Herbicide and pesticide use					
Logging on steep slopes					
Harvest of natural forests					

3. Below are listed some different values regarding the importance of forests in the watershed. How would you rank these values? (Place a 1 next to the most important value; place a 2 next to the second most important, a 3 next to the third most important, and so on down to 6 for the least important value.)

___ A place for recreation and relaxation.
___ A source of economic wealth and jobs.
___ A habitat for a variety of animal and plant life.
___ A way to balance and maintain the global ecosystem.
___ A way to protect the watershed's water, air and soil.
___ A way to preserve wilderness.

Section V Questions about the role of government

1. Do you think the watershed has been taking good care of?

☐ Strongly agree ☐ agree ☐ disagree ☐ strongly disagree

2. What do you think about the quality of watershed management planning

☐ Very good ☐ good ☐ no change ☐ poor ☐ very poor

3. What do you think about the cooperation among the reaches?

☐ Very cooperative ☐ cooperative ☐ poorly cooperative ☐ uncooperative

4. What do you think about the cooperation between agencies responsible for the management of the watershed?

☐ Very cooperative ☐ cooperative ☐ poorly cooperative ☐ uncooperative

5. Are you satisfied with the watershed planning and project decision-making process?

☐ Very satisfied ☐ satisfied ☐ dissatisfied ☐ dissatisfied

6. Do you think planning and decision making should involve public consultation?

☐ Very much ☐ some degree ☐ very little ☐ not at all

7. Are you satisfied with the watershed management practices in the watershed?

☐ Very satisfied ☐ satisfied ☐ dissatisfied ☐ very dissatisfied

8. Do you believe that watershed management is currently based on planning?

☐ Very much ☐ some degree ☐ very little ☐ not at all

9. Do you agree that there is sufficient funding for watershed management?

☐ Very much ☐ to some degree ☐ very little ☐ not at all

10. Which aspects of management practices are you dissatisfied with?
    A Forest management
    B Farming
    C Fishery
    D. Livestock husbandry
    E. Disaster prevention and control
    F. Water way protection
    G Soil and water conservation
    F Urban sprawl
    H Road development

11. How do you feel about the present provincial government's actions with regard to watershed management policy? (Circle one of the following.)

    A. the government is doing a very good job.
    B. the government is doing a good job.
    C. the government is doing a poor job.
    D. the government is doing a very poor job.

12. What do you think about the level of government spending on improving and protecting the environment? Are we spending: (Circle one of the following)

    A. too much money
    B. too little money
    C. about the right amount

13. What do you think about the level of government spending on environmental education? Are we spending: (Circle one of the following)?

    A. too much money
    B. too little money
    C. about the right amount

14. What do you think about the level of government spending on education? Are we spending: (Circle one of the following)

    A. too much money
    B. too little money
    C. about the right amount

Section VI Questions about public awareness and participation

1. Have you ever considered the health of the watershed?

☐ Very much ☐ some degree ☐ very little ☐ not at all

2. Have you ever thought of yourself as being a part of the watershed?

☐ Very much ☐ some degree ☐ very little ☐ not at all

3. Compared with other aspects of your life (e.g., your job, your hobbies), how important is watershed health to you? (Circle one of the following.)

   A. Most important
   B. Very important
   C. Fairly important
   D. Not very important

Why (or why isn't) watershed health important to you? (Please describe your views in a few sentences.)

____

____

4. Have you ever thought how your own actions might affect watershed health?

☐ Very much ☐ some degree ☐ very little ☐ not at all

5. Have you been particularly concerned about your personal safety in any of the following flood years?

☐ 1992 ☐ 1994 ☐ 1996 ☐ 1998 ☐ 2005 ☐ not at all

6. Have you heard or attended any kind of fora on watershed planning or project decision making processes?

☐ Very much ☐ some degree ☐ very little ☐ not at all

7. Would you like to participate in any kind of fora on watershed planning or project decision making processes?

☐ Yes ☐ No

8. Do you actively encourage friends, family, or coworkers to participate in helping to protect the environment? (Circle yes or no.)

   ☐ Yes ☐ No

9. Do you think of yourself as being a member of a group protecting the watershed? (Please circle the response that best describes how you personally feel about yourself regarding the watershed protectionist.)

   A. I identify myself very strongly as a member of a watershed protection group
   B. I identify myself somewhat as a member of a watershed protection group
   C. I do not think of myself as a member of a watershed protection group, but I do not oppose watershed protection groups.
   D. I oppose the watershed protection groups

10. Thinking about your friends, family, and coworkers, how strongly do you think they identify you as a member of a watershed protection group? (Circle one of the following.)

   A. Other people identify me very strongly as a member of a watershed protection group.
   B. Other people identify me somewhat as a member of a watershed protection group.
   C. Other people do not think of me as a member of a watershed protection group.
   D. Other people think I oppose watershed protection groups.

Section VII Questions about willingness to pay for improve watershed management

1. Please rank the following needs based on the difficulty in your daily life you have in obtaining or buying them (from 1 to 5. 5 is the most difficult to avail or buy)

   _____ Food
   _____ Clothing
   _____ Utilities
   _____ Clear Water
   _____ Electricity
   Others, please specify ___________________________________

2. An integrated watershed management is pursued sustainable development in terms of minimize the impact of the over developed one sector and compromised the other sectors in the watershed. Therefore, the development will surely affect some sectors interests in short-turn. Are you willing to support these changes?

   ☐ Yes ☐ No ☐ Not sure

3. As you possibly notice that unequal development of the watershed in terms of much poorer in upper reach and much richer in lower reach. The improper management practices in the upper reaches may affect lower reach. Do you believe that low reach should help upper reach?

4. Have you ever thought of doing sometimes, or contributing something to minimize the disaster?

   ☐ Yes ☐ No

5. Have you ever done sometimes consider to be minimized the disaster or enhance watershed environment?

   ☐ Yes ☐ No

   If yes, please specify____

6. Who do you think should be responsible for the watershed management?

   A. Every individual
   B. Industry
   C. Government
   D. Community
   E. All the above

7. Would you accept or not accept to pay something in terms of increased expenses such as tax or restoration fee in order to make it possible to carry out the watershed sustainable management program?

- ☐ I would definitely accept — go to question A
- ☐ I would probably accept — go to question A
- ☐ I would not accept — go to question B

A. What is the maximum increase in expenses that you would accept for this purpose?
Please remember that your income has to suffice for other expenses too!
Answer: Not more than______(Yuan) pre month during the restoration period.

C. Why, please explain____

8. What do you think can make different if you…

____

____

Section VIII Question for your suggestion:

1. Please give me you thought on how to manage the Min Rive Watershed?

2. What are you going to do for the watershed?

The End! Thank you again for your time and participation.

APPENDIX II. CERTIFICATE OF APPROVAL

The University of British Columbia
Office of Research Services and Administration
Behavioural Research Ethics Board

Certificate of Approval

PRINCIPAL INVESTIGATOR	DEPARTMENT	NUMBER
Innes, J.L.	Forest Resources Mgt	**B06-0763**

INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT
UBC Campus ,

CO-INVESTIGATORS:
Wang, Guangyu, Forestry

SPONSORING AGENCIES
Social Sciences & Humanities Research Council

TITLE :
The Social Conception and Impacts of Watershed Menagement in the Min River Basin, China

APPROVAL DATE	TERM (YEARS)	DOCUMENTS INCLUDED IN THIS APPROVAL:
OCT 31 2006	1	Aug. 24, 2006, Cover letter / Questionnaires / Agency approval

CERTIFICATION:

The application for ethical review of the above-named project has been reviewed and the procedures were found to be acceptable on ethical grounds for research involving human subjects.

Approved on behalf of the Behavioural Research Ethics Board
by one of the following:
Dr. Peter Suedfeld, Chair,
Dr. Jim Rupert, Associate Chair
Dr. Arminee Kazanjian, Associate Chair
Dr. M. Judith Lynam, Associate Chair

This Certificate of Approval is valid for the above term provided there is no change in the experimental procedures